U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-258 691

Automobile Emission Control The Technical Status and Outlook as of December 1974

Environmental Protection Agency, Washington, D C

Jan 75

278081

PB 258 691

AUTOMOBILE EMISSION CONTROL - THE TECHNICAL STATUS AND OUTLOOK AS OF DECEMBER 1974

A Report to the Administrator
Environmental Protection Agency

Prepared by

Emission Control Technology Division
Mobile Source Pollution Control Program

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

January 1975

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No. PB-258 691

4. Title and Subtitle
Automobile Emission Control - The Technical Status and Outlook as of December 1974 (A Report to the Administrator).

5. Report Date
Jan 75

6.

7. Author(s)

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Environmental Protection Agency, Washington, D. C.
Mobile Source Pollution Control Program.

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. Sponsoring Organization Name and Address

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstracts

This report is a summary of the current technical status and outlook in the automobile emission control field. This report has been prepared to supply information on the current status in the emission control technology area and to highlight the important technical issues that may arise during suspension hearings that EPA will hold if automobile manufacturers apply for a one-year suspension of the 1977 HC and CO standards.
This report contains a summary and evaluation of the development programs of 25 automobile manufacturers and other organizations involved in the development of automobile emission control technology.

17. Key Words and Document Analysis. 17a. Descriptors

*Air pollution control,
*Automobiles,
*Exhaust emissions,
Surveys,
Control,
Technology,
Fuel consumption,
Systems engineering,
Cost analysis,
Sulfates,
Catalytic converters,
Standards,
Hydrocarbons,
Carbon monoxide,
Manufacturers.

17b. Identifiers/Open-Ended Terms
Unregulated emissions,
Public hearings.

17c. COSATI Field/Group 13B, 13F

18. Availability Statement
National Technical Information Service
Springfield, Va. 22161

19. Security Class (This Report)
UNCLASSIFIED

20. Security Class (This Page)
UNCLASSIFIED

21. No. of Pages
210p.

22. Price
7.75/3.00

FORM NTIS-35 (REV. 10-73) ENDORSED BY ANSI AND UNESCO. THIS FORM MAY BE REPRODUCED USCOMM-DC 8265-P74

AUTOMOBILE EMISSION CONTROL - THE TECHNICAL STATUS AND OUTLOOK AS OF DECEMBER 1974

A Report to the Administrator
Environmental Protection Agency

Prepared by

Emission Control Technology Division
Mobile Source Pollution Control Program

January 1975

CONTENTS

1. INTRODUCTION 1-1

2. CONCLUSIONS. 2-1

   2.1 Conclusions 2-1
   2.2 Discussion of Conclusions 2-2

3. EMISSION CONTROL, TECHNOLOGY, AND FUEL ECONOMY 3-1

   3.1 General Factors that Influence Fuel Economy 3-1
   3.2 Effect of Emission Control Techniques 3-2
   3.3 Effect of Emission Standards. 3-2
   3.4 Oxidation Catalyst Systems. 3-4
   3.5 Advanced Oxidation Catalyst Systems 3-7

4. EMISSION CONTROL SYSTEM COSTS. 4-1

   4.1 Sticker Price Increases in Perspective. 4-1
   4.2 Component Costs of Emission Hardware. 4-2
   4.3 Cost of Emission Control Systems. 4-3

5. SULFATES AND OTHER UNREGULATED EMISSIONS 5-1

6. INDUSTRY STATUS. 6-1

   6.1 Industry Status - 1976 Model Year 6-1
   6.2 Industry Status - 1977 Model Year 6-1
   6.3 Industry Status - 1978 Model Year 6-4

7. INDIVIDUAL MANUFACTURERS REVIEWS 7-1

   7.1 Domestic Manufacturers. 7-1

      7.1.1 American Motors (AMC). 7-1
      7.1.2 Chrysler 7-6
      7.1.3 Ford 7-15
      7.1.4 General Motors (GM). 7-25

   7.2 Non-Automobile Manufacturer Status. 7-34

      7.2.1 Gould. 7-34
      7.2.2 Dresser. 7-41
      7.2.3 Yamaha 7-46
      7.2.4 Questor. 7-48

7.3 Foreign Manufacturers. 7-52

7.3.1 Alfa Romeo. 7-52
7.3.2 BMW 7-58
7.3.3 British Leyland 7-60
7.3.4 Daimler-Benz. 7-64
7.3.5 Fiat. 7-71
7.3.6 Honda 7-75
7.3.7 Izuzu 7-78
7.3.8 Mitsubishi. 7-71
7.3.9 Nissan. 7-85
7.3.10 Peugeot 7-90
7.3.11 Renault 7-95
7.3.12 Rolls-Royce 7-98
7.3.13 Saab. 7-104
7.3.14 Toyo Kogyo. 7-108
7.3.15 Toyota. 7-112
7.3.16 Volkswagen. 7-115
7.3.17 Volvo 7-118

8. APPENDIXES. . . . .

Appendix A. A-1
Appendix B. B-1
Appendix C. C-1

SECTION 1

INTRODUCTION

This report is a summary of the current technical status and outlook in the automobile emission control field. This report has been prepared for the Administrator of the U.S. Environmental Protection Agency (EPA) for two primary reasons:

(to supply information on

1. To inform the Administrator of the current status in the emission control technology area.

2. To highlight the important technical issues that may arise during suspension hearings that EPA will hold if automobile manufacturers apply for a one-year suspension of the 1977 HC and CO standards.

This report contains a summary and evaluation of the development programs of 25 automobile manufacturers and other organizations involved in the development of automobile emission control technology.

The time frame under consideration in this report is from the present until the 1978 model year. Special emphasis is given to the model years 1977 and 1978 since the emission standards for those years are different, and more stringent, than the current, model year 1975, emission standards. Although systems and concepts are currently under development that have a potential for introduction later than the above mentioned time frame they are not given major emphasis in this report. These longer term concepts will be included in next year's and subsequent reports. It should be noted that Congressional changes will result in the relocation of the longer term engine development programs to the Energy Research and Development Agency.

Most of the information in this report came from manufacturers' responses to a request from EPA. Most of the responses were received during the month of December 1974, so the information pertains to the period of time immediately prior to December 1974. This specification of the time to which the data relate is important in an area like emission control technology, in which rapid progress is being made. Copies of the responses submitted by the manufacturers are available for public inspection at the EPA Freedom of Information Center at the EPA Headquarters Building, 401 M Street, S.W., Washington, D.C.

Other data used in the preparation of this report were: a) 1975 certification results, b) 1976 Part I applications for certification, c) the technical literature, and d) the November 1974 report of the committee on Motor Vehicle Emissions*, National Academy of Sciences, called the 1974 NAS report in this report.

This report is the fourth in a series of reports on the same subject. The earlier reports were:

Automobile Emission Control - A Technology Assessment as of December 1971.
Automobile Emission Control - The State of the Art as of December 1972.
Automobile Emission Control - The Development Status as of April 1974.

These are References 2, 3, and 4 respectively.

The nomenclature used in this report for emission test results and standards is a triplet abbreviation. In this shorthand notation for example, the 1975 Federal standards of 1.5 grams per mile hydrocarbons, 15.0 grams per mile carbon monoxide and 3.1 grams per mile oxides of nitrogen are abbreviated 1.5 HC, 15.0 CO, 3.1 NOx with the understnading that the dimensions are grams per mile. Similarly, a vehicle that achieved 0.2 grams per mile hydrocarbons, 2.2 grams per mile carbon monoxide and 0.22 grams per mile oxides of nitrogen on a given test would be said to achieve the levels of 0.2 HC, 2.2 CO, 0.22 NOx.

The current emissions standards are thus:

1975/6	Federal; 1.5 HC, 15.0 CO, 3.1 NOx
1975/6	California; 0.9 HC, 9.0 CO, 2.0 NOx
1977	50-State; 0.41 HC, 3.4 CO, 2.0 NOx
1978	50-State; 0.41 HC, 3.4 CO, 0.4 NOx

---

* Reference 1 - Report by the Committee on Motor Vehicle Emissions, Commission on Sociotechnical Systems, National Research Council, National Academy of Sciences, Washington, D.C., November 1974.

SECTION 2

CONCLUSIONS

2.1 Conclusions

The conclusions listed below apply at the time this report was being prepared, December 1974. In a technical area like emission control technology where the rate of progress is so rapid, new developments may require modifications of conclusions that were made earlier.

The EPA report team concludes:

1. Control of HC emissions is currently the most critical area in the field of emission control, due to its relationship to air quality and fuel economy.

2. There is no inherent relationship between exhaust emission standards and fuel economy.

3. Delaying or relaxing emission standards cannot guarantee that gains in fuel economy will be made.

4. What the ultimate or final emission standards are going to be is more important than the length of any delay or temporary relaxation of the emission standards.

5. It is technically feasible to achieve any of the currently legislated emission standards.

6. Achieving the 1977 or 1978 emission standards with fuel economy equal to or better than current (model year 1975) vehicles is possible.

7. In the time frame considered by this report, the conventional engine is the only powerplant that can be considered for widespread application in automobiles.

8. Emission control technology has evolved to such a state that it is possible to meet the 0.9 HC, 9.0 CO, 2.0 NOx levels with lead tolerant systems.

9. The cost of systems that could be used to meet the 1977 standards of 0.41 HC, 3.4 CO, 2.0 NOx could be such that no additional cost penalty over current (1975) systems is incurred. However, lead time considerations are such that the more cost-effective technology may not be able to be applied to all vehicles by the 1977 Model Year.

10. Activity in the area of unregulated pollutant emissions, especially in the area of sulfate control technology development, is not commensurate with the degree of the problem.

11. The development of systems targeted toward the 0.41 HC, 3.4 CO, 2.0 NOx standards is moving ahead slower than considered necessary for successful certification with fuel economy equal to or better than current cars.

2.2 Discussions of Conclusions

1. There are four major reasons why HC control is the most important technical problem in the emission control area.

   a. The potential need for more HC control. The National Academy of Sciences, in their report on Air Quality and Automotive Emission Control*, stated:

   > "At least in the Los Angeles area, the Federal statutory hydrocarbon emission standard of 0.41 grams per mile may not be sufficiently stringent to ensure compliance with the national ambient air quality standard for oxidant. However, present analyses are inadequate to justify changes in the Federal motor vehicle emission standard for hydrocarbon at this time."

   Therefore HC control more stringent than the current 0.41 level cannot be ruled out, at least in some areas, on an air quality basis.

   b. The untreated HC emissions from conventional engines are strongly dependent on spark timing, as is fuel economy. Relatively more HC control will be required at spark timing calibrations that are optimum for fuel economy.

   c. HC emissions from automobiles come from other sources than the exhaust. The most important source, other than the exhaust, is evaporative HC emissions. The 1974 NAS report and the analysis by Heywood* both indicate that the actual evaporative emissions from in-use vehicles, based on EPA data, are greater than the current exhaust HC standard of 1.5 grams per mile. More work in the effective control of evaporative HC emissions and refueling losses is required. The change to the SHED-type technique, currently underway within EPA, should be accelerated, even if it means reordering present priorities, in the opinion of the report team.

---

* Reference 5 - Air Quality and Automotive Emission Control - A report by the Coordinating Committee on the Air Quality Studies, National Academy of Sciences and National Academy of Engineering, prepared for the Committee on Public Works, United States Senate pursuant to S. Res 135, approved August 2, 1973, Volume 1, Summary Report, September 1974.

d. The current EPA investigation of non-methane hydrocarbon (NMHC) exhaust emission standards for vehicles may have other more important ramifications than just making the vehicle emission standards consistent with the ambient air quality standards. The catalyst systems now being developed to meet low HC standards tend to have a higher percentage of methane in the exhaust than do the systems for which the current 0.41 gpm HC standard was derived. Therefore, if the standards were changed to a non-methane basis, the systems now under development could more easily meet the non-methane standard cooresponding to 0.41 HC. It may be possible to meet a non-methane standard without resorting to more sophisticated HC control techniques, although little data exists in this area. The potential exists, with a NMHC standard, to use some of the cushion that such a standard might have to improve fuel economy, but it must be pointed out that the use of the extra cushion that a NMHC standard might provide lies with the manufacturer.

2. The relationships between the exhaust emissions from a vehicle and the fuel economy it delivers are not simple. In this conclusion, the report team is in agreement with the 1974 NAS report.** The most important consideration involves the entire vehicle system that is used to achieve the exhaust emissions and fuel economy. The subject of emission and fuel economy interrelationships is discussed in more detail in Section 3 of this report.

3. There is no assurance that relaxation of emission standards will result in fuel economy gains. EPA does not have the authority to require that fuel economy gains be made. Additionally, at a given emission standard it is possible that several systems could be used to comply. These systems may have different fuel economy capabilities, and EPA cannot require that any certain system be used. The fuel economy performance of future vehicles will be a result of actions taken by automobile manufacturers, the same situation that has existed in the past and exists today.

---

* Reference 6 - Chapter Four of The Automobile and the Regulation of Its Impact on the Environment a report of the Legislative Drafting Research Fund of Columbia University under NSF grant NSF-GI-29965, June 30, 1974.

** 1974 NAS report (reference 1) page 31.

4. The long-term emission standards are more important than a temporary delay or relaxation of the emission standards. There are two major reasons for this.

a. Manufacturers must make near-term plans that are compatible with long-term plans. In the opinion of the report team, the automobile manufacturers cannot make firm plans for the near-term that will be compatible with long-term plans without knowledge of what the long-term emission standards will be. No manufacturer will risk shifting development and production toward systems that he feels will not be able to meet future standards. The long lead times for changeover and the desire to use tooling for as long as possible influence this attitude. The report team feels that if the industry was given the moratorium that they apparently desire, without the knowledge of what the emission standards will be after the moratorium, it would hinder instead of help development programs for future emission control systems. The industry, in all fairness, must know the long-term requirements that they will have to meet, and know them as early as possible. It is not exaggeration to say that these long-term targets could encompass the time frame up to and including the 1990's.

b. The long-term requirements must be communicated to the industry in such a way that the industry really believes that the requirements will be enforced. If the industry does not believe that the requirements will be enforced they will not make the required development and investment committments, in the opinion of the report team. An example of this is the current 0.4 NOx standard for model year 1978. Based on our review of the development programs targeted toward this requirement, the report team feels that the manufacturers do not believe this standard will ever be enforced.

Of course the long-term targets must be what is required for air quality. If a long-term requirement were set, and systems were developed toward that target, and subsequently more stringent levels were found necessary then the achievement of the new goal might be delayed because the systems that were developed to meet the previous targets might have no chance to meet the lower target.

5. In this conclusion concerning the capability to meet future emission standards, the report team is in basic agreement with the conclusions of the NAS in the 1974 NAS report*. The specific standards for the various model years are discussed more fully in Section 6.

---

* Reference 1, pages 1 and 2.

6. In general, the emission control systems that are required to meet future standards, while retaining improved fuel economy, are somewhat more costly, more sophisticated, or less well developed than are current systems. In general, the first cost increment paid for such improvements for fuel economy are less than the increments attributable to meeting the emission standards themselves.* These first cost increments are due to the development cost, and the investment cost, both of which are influenced by the lead time available for introduction of the improvements. Because of the lead time available for near-term introduction of the fuel economy improvements, some first cost increases are likely. Use of different types of technology may reduce or eliminate the first cost increases, but this requires the correct combination of development effort, investment, and lead time. An example of this is the system that is now under study by GM that incorporates a lean engine operation in conjunction with an oxidation catalyst. This system could be cheaper than conventional oxidation catalyst systems, since the air pump, EGR and EFE are eliminated.

7. New engine types can only be phased into production gradually, and then only after extensive development and testing programs. The 1974 NAS report** estimates that Diesel engined and CVCC engined automobiles could only account for 12 and 27 percent of domestic production, respectively, by 1980. The market share in 1977 and 1978 would be considerably less, and manufacturers might be pressed to meet the 1977 introduction dates estimated by NAS for these engine types, in the opinion of the report team.

8. The capability to certify at the California 1975 standards with a non-catalyst system has already been demonstrated by Saab. Other systems now under development, for example the Dresser carburetor, also show that the 0.9 HC, 9.0 CO, 2.0 NOx levels can be met with no catalysts. There are several implications inherent to this technical capability statement. First, if systems are built and sold that do not require lead-free fuel, the consumer will lose the maintenance advantages that accrue with lead-free fuel use. Second, at any emission level below the 0.9 HC, 9.0 CO, 2.0 NOx levels, lead tolerant systems will probably have inferior fuel economy to lead intolerant systems***. At this level the fuel economy may be about equal, comparing the Dresser results to catalyst systems, for example. Thirdly, if the standards are maintained

---

* Reference 7, Potential for Motor Vehicle Fuel Economy Improvement - Report to the Congress October 24, 1974, prepared by the U.S. Department of Transportation and the U.S. Environmental Protection Agency.

** Reference 1, page 114.

*** In This conclusion the report team is in agreement with the 1974 NAS report.

at the 0.9 HC, 9.0 CO, 2.0 NOx level, EPA's requirements for lead-free fuel cannot be supported on the basis that the only systems that can meet such levels are catalytic ones that require lead-free fuel. The report team estimates that by 1979, systems that do not require catalysts at the 0.9 HC, 9.0 CO, 2.0 NOx level could be in full production.

9. Systems like ones that employ a Dresser carburetor and an oxidation catalyst, or the lean engine calibration plus oxidation catalyst approach now under investigation by GM may be attractive from the cost standpoint. This is because the air injection system, EGR, and quick warm-up devices can possibly be eliminated, which would tend to lower system cost compared to 1975. On the other hand, system improvements like improved oxidation catalysts and enlarged exhaust manifolds may tend to add some cost. The overall cost result is difficult to estimate since such advanced systems are in the early stages of development, but the potential for lower or equal cost is there. Since the systems are in an early stage of development, the report team estimates that it will be difficult for all manufacturers to incorporate improved systems by 1977 on all models, especially those manufacturers who are not aggressively developing such systems now.

10. Many substances are emitted from vehicles for which there exists no emission standard. Among these substances are particulates (including lead and sulfates), aldehydes, and polycyclic organic matter (POM). In the area of particulate emissions for example, before any meaningful characterization of the particulate emissions from vehicles is done, those who characterize the particulates should know what are the most important health related parameters for particulate emissions*. This is important since the characterization work and the attendant procedures could be much different if particulates were important on just a total mass basis, or on the basis of a size distribution, or the basis of a specific particulate material, or on the basis of some combination of total mass, size distribution and specific material. In the area of particulate emissions, the relative lack of adequate health effects data makes interpretation of the existing data difficult. This is especially important for the investigation and characterization of alternate engine concepts such as the Diesel.

The unregulated pollutant given the most emphasis in the past year or so has been sulfate. Characterization work has progressed, but relatively little in the area of control technology development, aside from a small EPA effort, has been done. The report team concludes that the manufacturers are waiting to see if EPA thinks sulfate emissions from automobiles will be a health hazard. If EPA does consider sulfate emissions a problem, and does not act to lower fuel sulfur levels, then the industry will start working on control technology, in the opinion of the report team.

---

* In recognizing this lack of basic information about the health related aspects of particulates, we are in agreement with the NAS, reference 3.

11. Development is moving ahead slowly, in the opinion of the report team, because of self-imposed industry constraints.

The determination of the reasonableness of the various self-imposed constraints (e.g. first cost, development cost, performance, etc.) will have to be made by the Administrator.

SECTION 3

EMISSION CONTROL TECHNOLOGY AND FUEL ECONOMY

The subject of automobile fuel economy has received an increasing level of attention lately as U.S. dependence on foreign crude is increasing. Many factors influence the fuel economy an automobile will deliver, including calibrations and modifications made to meet exhaust emission standards. It is the intent, in this section, to explain the relationship between emissions and fuel economy so that the inadequacy of the cliches about emissions and economy can be fully understood.

3.1 General Factors that Influence Fuel Economy

To establish the proper perspective it should be understood that the design and calibration of an emission control system are only two of the many factors which influence automobile fuel economy. The multitude of factors can be subdivided into operational and design factors.

Operational Factors

The manner in which a vehicle is used has a significant effect on the fuel economy of that vehicle. Among these operational factors are vehicle speed, length of trip, engine temperature at the beginning of a trip, ambient temperature, wind velocity, type of road surface, type of terrain, altitude, the manner in which the vehicle is driven (smoothness of driving and acceleration/braking habits), state of tune of the engine, tire inflation pressure, and others.

Design Factors

The design and optimization of the entire engine/vehicle system also has a significant effect on fuel economy of a given vehicle. These engine/vehicle design factors include vehicle weight, engine type, engine design, emission control system design and calibration, horsepower, compression ratio, vehicle size and shape, transmission type and design, axle ratio, tire design and construction technique, and convenience devices such as air conditioning, power steering and others.

Ranking of Factors

It is extremely difficult to quantify the effect any individual factor will have on fuel economy without knowing the values of all the other factors. The fuel economy effect of a change in vehicle shape, for example, depends on the way the vehicle is driven. Streamlining has little or no effect during slow speed, stop and go driving but it can have a substantial effect during high speed highway driving.

Holding operational factors constant, the EPA certification tests for 1975 showed differences in design factors accounted for up to 300% differences in urban cycle fuel economy.

Holding design factors constant, EPA data show the difference between typical city-type driving and highway type driving results in a 50% difference in fuel economy. The addition of other operational variables such as ambient temperature, can result in substantially greater differences.

3.2 Effect of Emission Control Techniques

Although the cliche that "Emission control reduces fuel economy" is very popular and often very true, it is a generalized statement that is invalid when considering certain control approaches. Acceptance of such a cliche as an indisputable fact could lead to erroneous conclusions about the capability to simultaneously achieve improvements in emissions and economy.

Some of the specific emission control related factors that affect both the emissions and fuel economy of current engines are air/fuel ratio and air/fuel ratio control, spark timing and spark timing control, degree of exhaust gas recirculation (EGR) and methods of EGR control, choke time, calibration and quick warm-up device control, intake air temperature control, choice of exhaust gas aftertreatment type, and system optimization. Table 3.2.1 gives the general effects these factors have on fuel economy and exhaust emissions. The varied effect of different emission control techniques such as the ones listed in Table 3.2.1 indicate that it is not enough to know the directional effect of a system change on exhaust emissions to deduce the directional change in fuel economy. Some of the most effective control techniques, such as catalytic converters, have no effect on fuel economy. The use of such devices allows the "decoupling", as NAS put it*, of emission control and fuel economy. Aftertreatment devices such as catalysts and thermal reactors only affect fuel economy to the extent that engine calibration changes are made to optimize their effectiveness. With lean thermal reactors or catalysts, low emission levels can be achieved using engine calibrations for optimum fuel economy.

3.3 Effect of Emission Standards

The net effect on fuel economy of a given emission standard depends on the combination of control techniques used to achieve compliance. Analysis of EPA certification data has clearly shown that the fuel economy performance of nominally identical cars (e.g. same weight, engine size, axle ratio, etc.) can be significantly different while the emissions are nearly the same. The difference in fuel economy is the result of the difference in the usage of fuel efficient control technology. At a fixed emission level fuel economy is a function of the usage of fuel efficient control technology.

---

* Reference 1.

Table 3.2.1

Impact of Various Emission Control Techniques on Fuel Economy

Technique	Pollutants Controlled	Fuel Economy Effect
1. Retarded Spark Timing	HC, NOx	Negative
2. Rich air/fuel ratio	NOx	Negative
3. Lean air/fuel ratio	HC, CO, NOx	Positive
4. Port EGR	NOx	Negative
5. Proportional EGR	NOx	None or Positive
6. Quick Heat Intake Manifold w/fast choke	HC, CO	Positive
7. Heated intake air	HC, CO	Positive
8. Air injection	HC, CO	Almost none
9. Oxidation catalyst	HC, CO	None
10. Reduction catalyst	NOx	None
11. Thermal reactor	HC, CO	None
12. Reduced compression ratio	HC, NOx	Negative

Erroneous conclusions about emission control and fuel economy can result from ignoring differences in the control technology available and looking at the effect of different levels of emission control using a particular control system. With a fixed emission control system fuel economy is a function of the degree of emission control required. When alternative control approaches are not considered, changes in emission level can only be achieved by altering basic engine calibrations such as spark timing. Since minimum emissions and maximum fuel economy are usually not simultaneously achieved, lower emission levels with a given system result in degraded fuel economy.

Besides looking at emission control system/emission level/fuel economy relationships with the control system held constant or the emission levels held constant, it is also possible to consider the fuel economy level held constant. With a fixed level of fuel economy the degree of emission control achievable depends on the type of control technology used. For example, the change in emission level from uncontrolled to the 1975 Federal Interim levels (1.5, 15, 3.1) has been accomplished at a fixed fuel economy level by selection of lean engine calibrations and catalytic exhaust treatment systems.

The three underlined statements above are three different ways of looking at control system/emission level/fuel economy relationships. Each statement is a two-dimensional analysis of a three dimensional problem, however. Unless one fully understands the three dimensional aspects of the tradeoffs involved, it is possible to be misled about the expected impact of a particular emission standard. Since there is no fixed relationship between fuel economy and emission standards, it is impossible to guarantee a change in fuel economy by a change in emission standards.

Appendix B contains further discussion of this topic.

3.4 Oxidation Catalyst (OC) Systems

The basic oxidation catalyst system used on 1975 model cars is capable of providing about a 60% reduction in hydrocarbons and a 70% reduction in carbon monoxide at 50,000 miles. If a manufacturer nominally calibrates to 70% of the HC and CO standard and 80% of the NOx standard to achieve a high probability of passing then his high-mileage goal when certifying to the 1975 Federal standards would be:

HC = 1.5 x .7 = 1.05
CO = 15. x .7 = 10.5
NOx = 3.1 x .8 = 2.5

with catalyst efficiency of 60%/70% for the HC and CO the "raw" or "untreated" emission levels he must target for are:

HC = 1.05 ÷ (1-.6) = 2.63
CO = 10.5 ÷ (1-.7) = 35.0
NOx = 2.5 ÷ (1-0) = 2.5

If these emission levels can be achieved without resorting to emission control techniques which detrimentally effect fuel economy, then it is possible for the manufacturer to market an oxidation catalyst equipped vehicle that complies with the 1975 Federal standards yet has excellent fuel economy. Note that the untreated emission levels shown above are higher than were required to meet the much less stringent 1974 emission standards without catalysts. With the same safety factors the nominal emission levels needed to meet the 1974 standards were:

HC = 2.8 x .7 = 1.96
CO = 28. x .7 = 19.6
NOx = 3.1 x .8 = 2.5

The addition of the catalytic control system on 1975 models resulted in 50% reductions in tailpipe HC and CO levels but allowed 35% and 75% increases in the "raw" emissions of HC and CO respectively. The catalyst system gave manufacturers the flexibility to re-optimize the basic engine for fuel economy by shifting some of the emission control burden to an aftertreatment device. The unleaded fuel required for use with oxidation catalysts necessitated the use of low compression ratios (which were phased in beginning in 1971) in order that the engine would be satisfied on the generally available 91 RON lead free fuel. While the use of low compression ratio in itself can be expected to degrade fuel economy by approximately 5% compared to a "regular fuel" engine, the unleaded fuel causes less emission deterioration at high mileage which provides additional flexibility in determining engine calibrations.

The combined effect of using catalysts and lead free fuel on the 1975 models has resulted in a level of fuel economy for many cars which is equal to or higher than the fuel economy achieved by pre-1968 models which were not emission controlled. As shown in Figure 3.4.1, the average 1976 model is now slightly better than the average 1967 model. The emission control approaches which caused the nominal 12% economy losses in 1974 have been less extensively used in 1975, because they were not needed with oxidation catalyst systems.

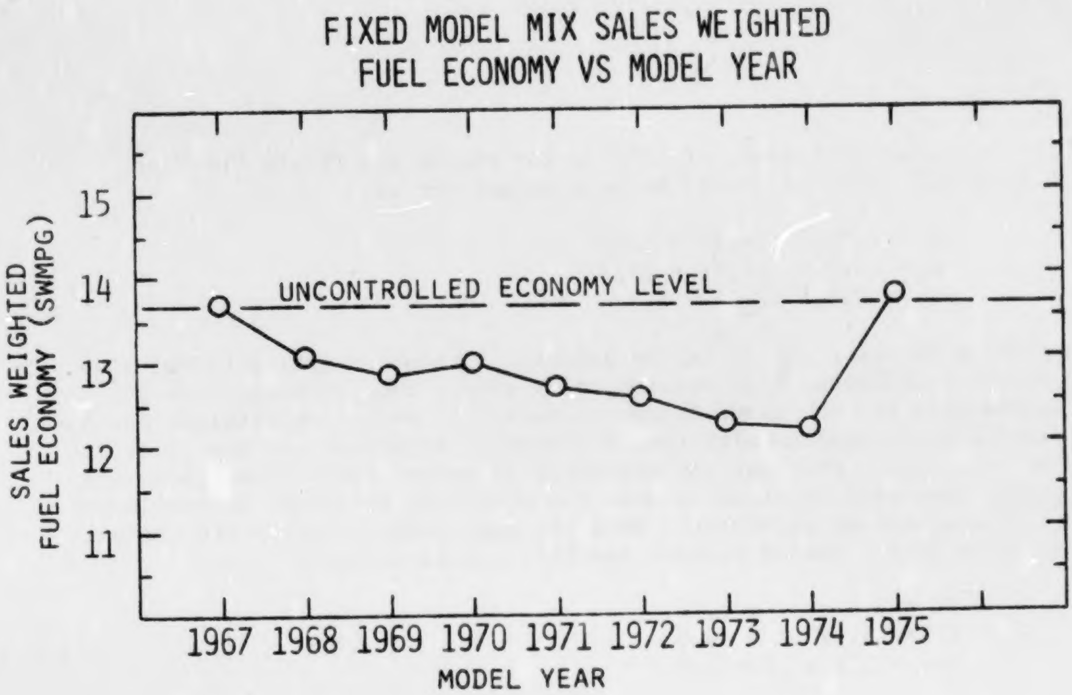

FIXED MODEL MIX SALES WEIGHTED
FUEL ECONOMY VS MODEL YEAR
SALES WEIGHTED FUEL ECONOMY (SWMPG)
15
14
13
12
11
UNCONTROLLED ECONOMY LEVEL
1967
1968
1969
1970
1971
1972
1973
1974
1975
MODEL YEAR

Figure 3.4.1

The hard data now available prove emission standards as stringent as the 1975 Federal Interim standards can be achieved with fuel economy equal to or better than the fuel economy of 1967 model cars. This is not to say emission controls have no effect on fuel economy. The industry now has the technology in hand to do somewhat better than the fuel economy of their 1975 models since some engine efficiency compromises (e.g. low compression ratio, some spark retard, etc.) are still made to meet the 1975 Federal standards. Obviously some manufacturers are making more compromises than others (notably Ford, BMW, Toyota and Volvo) due to the use of inadequate or inefficient aftertreatment systems. The reason that a fuel economy loss is no longer apparent for the new car fleet as a whole is that some of the technology developed to reduce emissions (e.g. quick heat intake manifolds, high energy ignition, etc.) actually tended to improve the fuel economy potential of the car. Had such technologies been adapted to uncontrolled automobiles, fuel economy superior to that achieved by the 1975 model catalyst car could have been realized. It is unlikely, in the opinion of the report team, that the costs of developing such technologies would have been accepted by the auto industry without the incentive provided by the emission standards.

3.5 Advanced Oxidation Catalyst (AOC) Systems

The level of fuel economy associated with emission standards more stringent than the 1975 Federal Interim standards depends on the types of control systems developed and used by the industry to meet the standards. As shown in table 3.5.1, a reduction in emission standards from the 1975 49-state values of 1.5, 15., 3.1 to the 1975 California values of .9, 9., 2.0 resulted in about a six percent drop in fuel economy, on the average, using a fixed model mix for both the 49-state and California fleets of each manufacturer. Note, however, that not all manufacturer suffered losses in meeting the more stringent levels. Manufacturers who used a more sophisticated approach on their California cars experienced smaller losses or even improvements in economy on their California cars. Ford, for example, used full catalytic treatment on their California models but not on their 49-state cars. Saab used a more sophisticated EGR system and air injection on their California cars. Volkswagen used catalytic aftertreatment to a greater extent in California.

Table 3.5.1

"49-State" vs. "California" Cars

Manuf.	49-State Economy	California Economy	Percent Change
General Motors	14.53	13.17	-9.4%
Ford	10.90	10.93	+.3%
Chrysler	15.56	14.22	-8.6%
American Motors	17.18	14.67	-14.6%
Volkswagen	21.32	22.23	+4.3%
Toyota	19.07	18.08	-5.2%
Nissan	21.56	21.33	-1.1%
Volvo	16.13	16.27	+.9%
Peugeot	19.20	18.69	-2.7%
Audi	21.06	20.94	-.6%
Saab	20.70	21.60	+4.4%
		arithmetic average	-2.9%
		sales weighted average	-5.7%

To achieve compliance with standards that are lower than the 1975 Federal and California standards, manufacturers have two approaches open to them:

1. Recalibration of 1975 systems for lower emissions.

2. Use of improved emission control systems for lower emissions without adversely affecting engine calibrations needed for good economy.

Some of the emission control techniques that could be used when taking the second approach include:

1. Improved "Quick-heat" intake systems (SEFE)
2. Start catalysts
3. Proportional EGR (PEGR)
4. Modulated air injection (MAIR)
5. Improved thermal treatment of exhaust gas
6. Sonic carburetion

7. Electronic spark control
8. Improved catalysts
9. Cold storage of HC emissions
10. On-board fuel distillation

Each of these techniques has been reduced to hardware and successfully emission tested. The available test data indicate that when one or more of these advanced control techniques are integrated into the basic 1975 model oxidation catalyst system, it is possible to achieve lower emissions without adversely affecting fuel economy.

Improved Quick-Heat Intake Systems

Quick-heat intake systems reduce cold start enrichment requirements by transferring exhaust gas heat to the intake manifold during warm-up. On several 1975 models a form of quick-heat system is used which consists of a vacuum activated valve installed at the exhaust manifold outlet on one side of a V-8 engine. During cold start the valve is closed and exhaust gases are forced through the exhaust crossover passages in the intake manifold to the opposite exhaust manifold. As the exhaust passes through the intake manifold passages, heat is transferred to the "fresh" intake charge through the walls of the exhaust crossover.

A more sophisticated application of the Quick-heat technique is the Super Early Fuel Evaporation (SEFE) system which was designed by GM. As shown in figure 3.5.1, the SEFE system is plumbed so that both banks of exhaust gas are diverted to the intake manifold on cold starts. A special plate, designed to promote efficient heat transfer, separates the exhaust passage from the fresh mixture.

Start Catalysts

A "start" catalyst or "warm-up" catalyst is a low thermal inertia oxidation catalyst which is used upstream of the main catalyst in a catalyst control system. The performance criteria for the start catalyst are similar to those for the main catalyst but rapid light-off is given a much higher weighting and durability and resistance to "breakthrough" can be much less important. A drawback to the catalytic control approach has been that efficient pollutant control does not occur until the catalyst bed has reached about 400°F. In order to achieve this temperature rapidly, it is desirable to mount the catalyst very near the engine's exhaust ports, keep the thermal inertia of the catalyst low, and keep the volume of the catalyst low. Durability, resistance to "breakthrough" (inadequate catalyst volume to convert high exhaust volumes), high warmed-up conversion efficiency and other such considerations, however, make it impractical to select a catalyst and catalyst location solely because of its light-off characteristics. The logical way to avoid the compromising of warm-up performance is to use two catalysts, one for warm-up and one for stabilized conditions. The optimum start catalyst plumbing arrangement would be one that completely removes the exhaust gas from the start catalyst once the main catalyst has reached its light-off temperature. In this way the start catalyst is not subjected to the deteriorating influence of the exhaust stream any more than is absolutely necessary. Figure 3.5.2 shows a possible plumbing arrangement for a start catalyst system. Other designs which remove the exhaust stream from the start catalyst have been developed by GM. Ford and Chrysler have experimented with start catalysts that are left on stream all of the time. Table 3.5.2 shows the reduction in emissions achieved by Chrysler with their start catalyst system which diverts 100% of the exhaust gas to the start catalyst during warm-up but only 50% during stabilized conditions.

Table 3.5.2

Effect of Start Catalyst on Composite Emissions
Chrysler Data - 400 CID, C-Body

	HC	CO	NOx
1. Two test average without start catalyst	.37	2.7	1.35
2. Three test average with start catalyst	.20	1.4	1.35
Emission ration, 2/1	.54	.51	1.0

Ford has experimented with small radial flow monoliths, close coupled to the exhaust manifolds, which approximately had double the HC and CO conversion efficiency during the cold portion of the emission test. Ford did not report data on a system employing both the small start catalyst and the main catalyst.

Proportional EGR

EGR systems that are capable of delivering an optimum schedule of recirculated exhaust gases are necessary if the adverse impacts that less sophisticated systems have had in the past are to be eliminated. While there is no EGR system yet in production that has been shown to provide optimum scheduling, several systems such as the GM back-pressure modulated system, appear to be better than others. No system currently in use, as far as the report team could determine, takes advantage of the increased EGR tolerance which conventional engines are known to have at higher loads. The report team concludes that more development work in the EGR area is required since few manufacturers have been able to provide the EGR rate versus load information which EPA has specifically requested to be included in annual status reports for the last two years.

Modulated Air Injection

It has long been recognized that an optimum air injection rate exists for every operating condition of the engine. An inadequate exhaust O_2 level results in less than optimum tailpipe emission levels whether a catalyst is used or not. Excessive O_2 levels tend to quench reactions in the exhaust manifold and catalyst. In general, it is desirable to maintain an air injection rate that keeps the percentage of oxygen in the exhaust stream constant. Most current AIR systems increase air flow as engine speed increases but decrease flow as engine load increases. Relatively simple modulating valves, already mass produced, are capable of making a conventional AIR system deliver air in proportion to engine load.

Preliminary tests at Ford demonstrated that 13-27% reductions in HC emissions can be achieved by modulating air injection.

Sonic Carburetion

The theoretical capability of lean mixtures to simultaneously reduce HC, CO and NOx emissions is well known. Achieving a consistent, well vaporized or atomized mixture of air and fuel during transient operation is, however, difficult. The fact that conventional carburetors can be used to deliver extremely lean (18:1-19:1) air/fuel ratios on an overall basis does not mean the theoretical benefits of lean mixtures will actually be achieved. However, a sonic mixing device, developed by Dresser Industries, has demonstrated the capability to achieve the mixture uniformity necessary to realize the theoretical advantages of lean mixtures.

Dresser equipped vehicles tested by EPA and others have demonstrated that the level of "untreated" emissions necessary to achieve the 1977 Federal Standards (.41, 3.4, 2.0) with a catalytic aftertreatment system can be achieved with excellent fuel economy. In order to achieve the 1977 standards the pre-catalyst emission levels need to be:

$$\mathrm{HC} = .41 \div (1-.6) = 1.03$$
$$\mathrm{CO} = 3.4 \div (1-.7) = 11.33$$
$$\mathrm{NOx} = 2.0 \div (1-0) = 2.0$$

Levels lower than these have been demonstrated by Dresser on several vehicles. EPA knows of no instances where Dresser has been unable to achieve these levels when high volume exhaust manifolds are used to promote the thermal oxidation of HC and CO in the exhaust. Even without catalysts Dresser test vehicles have approached or equaled the 1977 standards when some spark retard is used to reduce HC. The use of a catalyst will, in the opinion of the report team, allow Dresser equipped vehicles to simultaneously achieve fuel economy that is superior to the economy achieved by typical vehicles in any previous model years, including uncontrolled. Typical non-catalyst emission levels for Dresser equipped vehicles are shown in table 3.5.3.

A more extensive discussion of the Dresser system can be found in Section 7.2 of this report.

Cold Storage of HC Emissions

The cold storage concept is only effective on HC emissions. Since, however, HC emissions are to be the critical pollutant when trying to achieve the 1977 standards with high fuel economy, it may be a useful addition to future emission control systems. The idea of the cold storage system is to trap hydrocarbon emissions in a charcoal adsorber during cold start and warm up operation. This is similar in concept to the technique currently used to control evaporative emissions but on a larger scale. During the first few minutes of engine operation the exhaust gas is directed through a bed of activated charcoal after it passes through the catalyst. The size of the bed required is approximately equal to the size of the catalytic converter. When the catalyst reaches light off temperature, the air pump is used to purge the hydrocarbons stored in the adsorber into the catalyst where they are very efficiently oxidized. A schematic of the cold storage system is shown in Figure 3.5.3.

Both Daimler-Benz (Mercedes) and General Motors have experience with the cold storage approach and both have reported data which shows the system to be highly effective. As early as 1971 GM reported 30% reductions in HC emissions with the use of this system. Work was stopped on the system because it "requires such complicated pipes and valves -- it is too impractical for production consideration at the present state-of-the-art".

GM reactivated cold storage work when it appeared that high HC emissions would keep their rotary engine from certifying in 1975. This fact gave some indication to the report that the cold storage system may not be as impractical as previously indicated, since it was resorted to when the desire to certify a particular engine was high.

Figure 3.5.4, provided by Daimler-Benz, shows an engine's HC emission rate with and without the use of a cold storage system. With this system, cold start HC emissions are essentially eliminated. This reduces the need to employ alternate HC control methods which may have a detrimental effect on fuel economy. When used inconjunction with catalyst systems, cold storage systems have been shown to cause HC reductions between 30% and 80%. Data on a rotary engine test car are shown in table 3.5.4.

Table 3.5.3

Dresser Test Results
No Catalysts

Vehicle	Inertia Weight	'75 FTP Emissions HC	CO	NOx	FTP MPG	Typical Uncontrolled Car of Same Weight, MPG
Ford 351 CID w/Dresser carb and large exhaust manifold.	4500	.41	4.7	1.30	11.3	12.2
Chevrolet 350 CID w/Dresser carb and std. manifolds	4500	.88	4.7	1.70	12.9	12.2
Chevrolet 350 CID w/Dresser carb and std. manifolds	4000	1.18	6.0	1.16	13.4	13.2
Capri 2600 cc w/Dresser carb and large exhaust manifolds	3000	.37	3.9	1.29	17.0	16.1
Levels needed to certify at .41, 3.4, 2.0 with catalysts		1.03	11.3	2.0		

Table 3.5.4

Effect of Cold Storage
1972 FTP
(1977 Standards would be .46, 4.7, 2.0
on the above procedure)

	HC	CO	NOx
GM test car without cold storage	1.03	2.2	1.5
With cold storage for first two minutes	.21	2.2	1.5

Electronic Spark Control

Conventional spark modulation systems change the timing by measuring only:

1. engine speed
2. manifold vacuum

Some late model emission controlled cars also provide a simple on-off control over the vacuum advance mechanisms as a function of:

1. transmission gear selection
2. engine speed
3. vehicle speed
4. engine temperature

Some models also employ spark delay valves which dampen the application of advance provided by the intake manifold vacuum.

Despite the additional spark modulation which has been used in recent years, much more needs to be done in the spark modulation area if fuel economy is to be optimized at a given emission level. Step changes in spark advance which are now made on many vehicles, need to be replaced with smooth and continuous modulation that is a function of many additional variables including:

1. inlet air temperature
2. humidity
3. barometer
4. throttle position

More sophisticated spark control systems appear to be under intensive investigation by Chrysler and others. The potential for fuel economy improvements in the 5% range appear feasible with this type of system.

On-Board Fuel Distillation

Many of the emissions which are generated during the cold start portion of the emission test are the result of the rich air/fuel ratios necessary to achieve a combustible mixture of atomized and vaporized gasoline and air with cold engines. Devices discussed earlier, such as Super EFE, are effective at shortening the period of time that rich mixtures are required by rapidly providing heat to the intake manifold. Other devices, such as the Dresser sonic carburetor, reduce or eliminate the need for mixture enrichment by improving the mixture preparation to the point that little or no enrichment is required even with a cold engine. If a more volatile fuel than gasoline could be used during warm-up operation then adequate mixtures could be achieved with conventional engines. Gaseous fuels such as CNG and LPG have been shown to reduce cold start enrichment requirements and cold start emissions but LPG and CNG are not feasible replacements for gasoline because of supply and handling problems. However, a means of obtaining a supply of volatile fuel from gasoline to be used only during cold starts, has been developed and several manufacturers reported the effect of such an approach on exhaust emissions.

A volatile supply of fuel for use during cold starts can be obtained by distillation of regular gasoline. By using heat to separate the more and less volatile fractions it is possible to divide the fuel supply once it is taken into the main fuel tank of the vehicle. A system developed by Mobil Oil uses electrical resistance to distill off the ligher fractions of gasoline and save them for use during cold start only. After vehicle shut down the fuel in carburetor's float bowl is pumped back to the main tank and the float bowls are re-filled with LEF (low emissions fuel) from the separate holding tank. With LEF used for start up, enrichment is not required and HC and CO levels can be significantly reduced. After the engine becomes sufficiently warm to use heavier fuel, the LEF tank is turned off and the main fuel tank supplies the carburetor and provides enough fuel to the LEF generator to replenish the LEF tank. LEF replenishment can be accomplished in about five minutes under normal conditions.

Data reported by Rolls Royce showed reductions of 44% and 28% for CO and HC respectively when the LEF system was used on a non-catalyst car. Since the LEF system reduces emissions during the time period prior to catalyst light-off, the emissions reductions would be expected to be larger with a catalyst system where the cold start emissions are a larger fraction of the total emissions. Saab did test the LEF system on a catalyst car and showed the results in table 3.5.5.

Table 3.5.5

Effect of On-Board Fuel Distillation
1977 Saab Prototypes

	HC	CO
Without LEF system	.25	1.29
with LEF system	.12	.70
% reduction with LEF	52%	46%

Saab indicated that they have no plans to use the LEF system in production because they admit they can meet the statutory 1977 standards without it. Other manufacturers who claim they cannot meet the standards seem to be less interested in on-board fuel distillation.

GM has not recently reported any work in the on-board fuel distillation area but they were one of the early leaders, achieving 50% HC reductions and 75% CO reductions during the cold phase of the test several years ago. A schematic on the system tested by GM is shown in figure 3.5.5.

Improved Thermal Treatment of Exhaust Gas

Intelligent design of exhaust ports and exhaust manifolds can result in significant reductions in CO and particularly HC emissions compared to conventional, uncontrolled engine designs. If the exhaust gases can be held at high temperature for a period of time, oxidation reactions continue to occur. Several means of holding the exhaust gas at a higher temperature for a longer period of time are available:

1. exhaust port liners
2. high volume exhaust manifolds
3. insulated exhaust manifolds
4. exhaust manifold baffling

Chrysler data shows HC reductions of up to 70% with the use of port liners and Ford data shows HC reductions of 22% are possible on some of Ford's engines when higher exhaust manifold volumes are used.

Improved Catalysts

The difficulty associated with the 1977 emission levels of .41 HC, 3.4 CO, 2.0 NOx is inversely related to the efficiency of oxidation catalysts available to the manufacturer. The more of the emission control burden that can be shifted off onto the aftertreatment system, the easier it becomes for any standard to be achieved and the easier it becomes to optimize for fuel economy. The improvement in catalyst performance that has been realized in the past five years has been significant and their is no reason to expect that the catalysts used on the 1975 models represent the ultimate in performance. Ford reported that they expect substantial improvements in catalysts efficiency due to the use of larger catalyst volumes on 1977 models.

Summary

The sub-systems discussed above are just examples of the possible control approaches that can be used to produce low emissions and high fuel economy simultaneously. Some of these systems are complicated compared to typical 1975 systems but they are not all required to achieve the 1977 standards with good fuel economy. Some of these subsystems (e.g. Dresser carburetor) may turn out to be simpler and less expensive than the components they replace. Provided the necessity to meet stringent emission levels in the future is accepted by a manufacturer, the report team predicts the cost and complexity associated with any emission standard will continue to decrease with time.

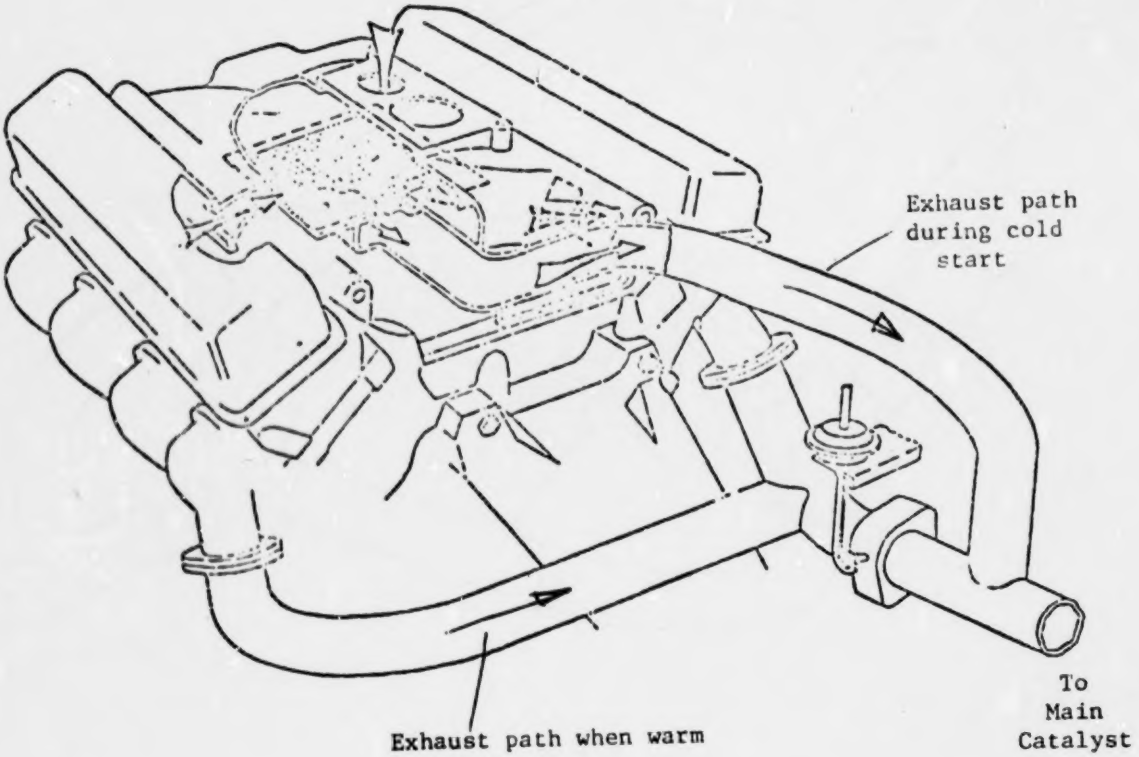

Exhaust path
during cold
start
Exhaust path when warm
To
Main
Catalyst

Figure 3.5.1
Super EFE

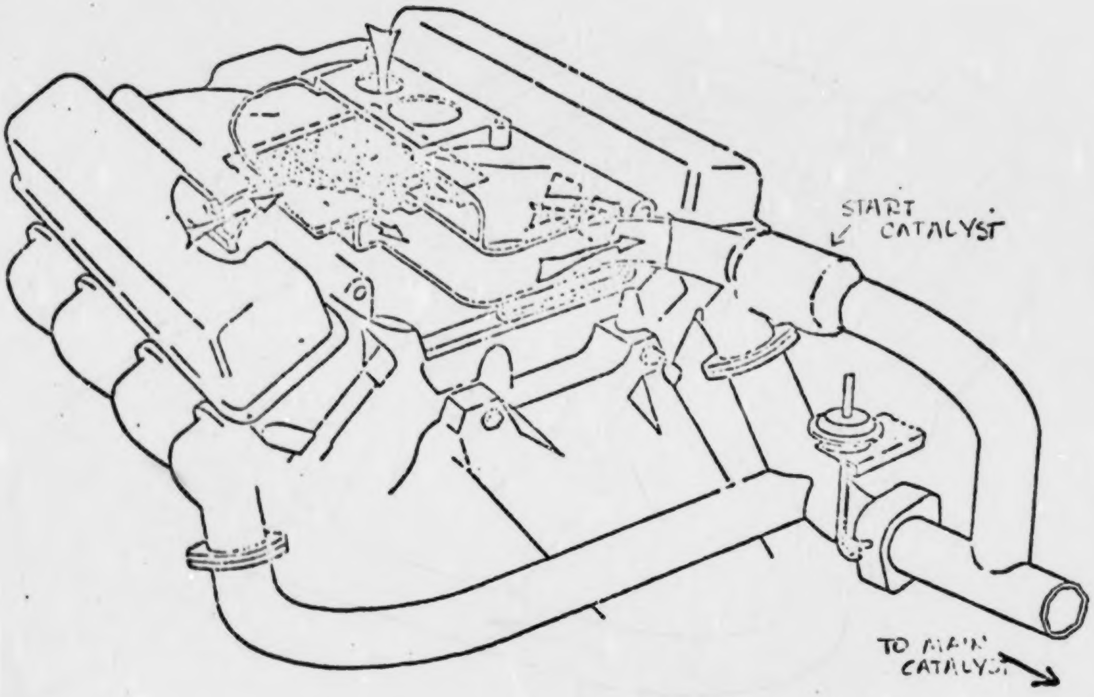

START CATALYST
TO MAIN CATALYST

FIGURE 3.5.2
START CATALYST SYSTEM

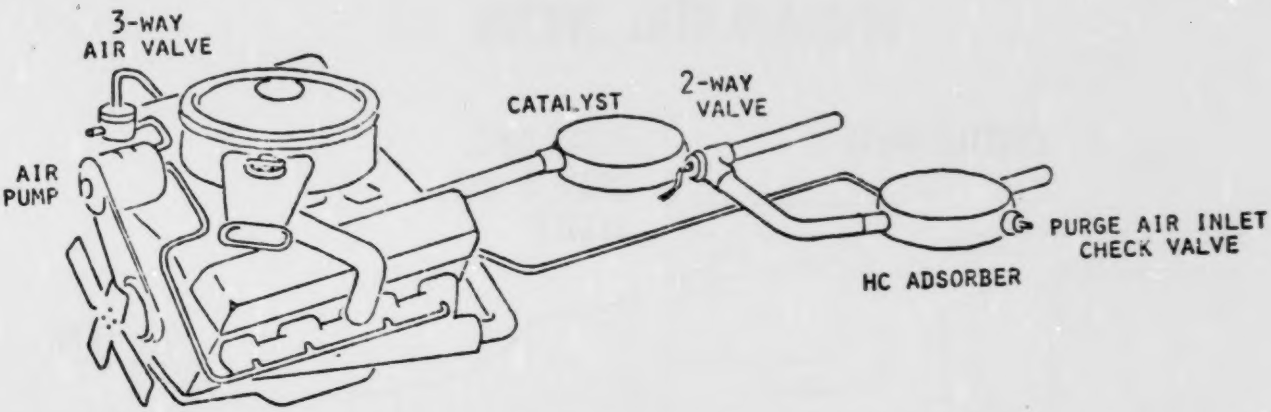
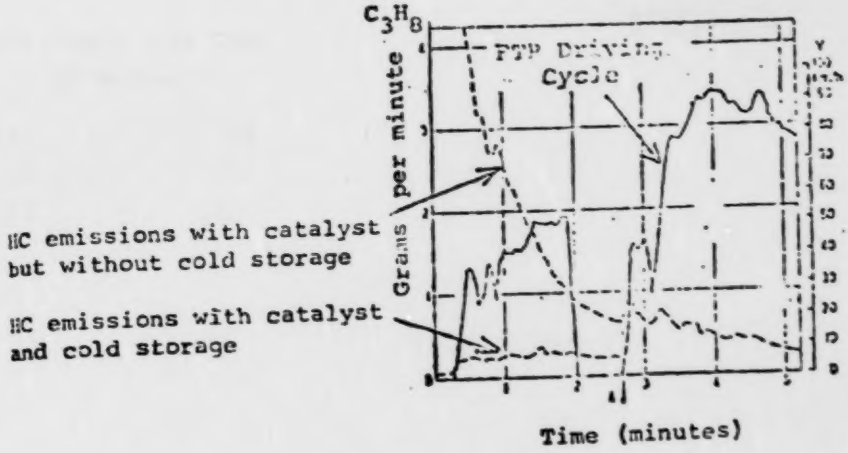
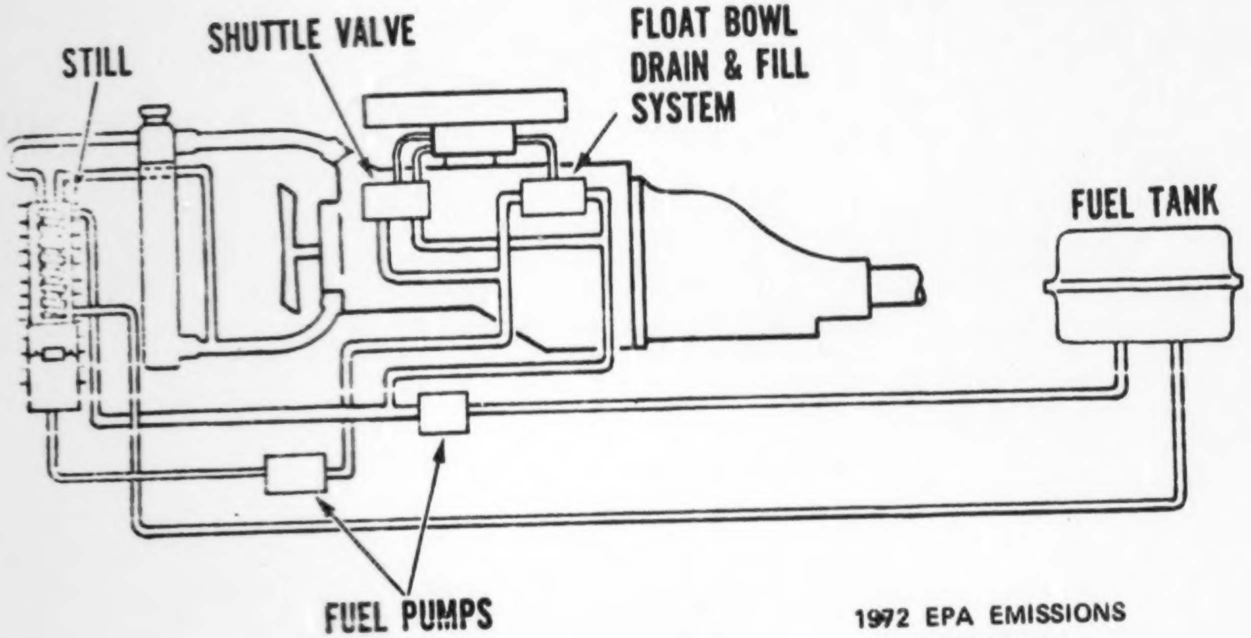

3-WAY
AIR VALVE
AIR
PUMP
CATALYST
2-WAY
VALVE
PURGE AIR INLET
CHECK VALVE
HC ADSORBER

Figure 3.5.3 - Cold Storage System


HC emissions with catalyst but without cold storage

HC emissions with catalyst and cold storage

Figure 3.5.4 - HC Emission Rate with and without Cold Storage



ON BOARD STILL SYSTEM

STILL
SHUTTLE VALVE
FLOAT BOWL DRAIN & FILL SYSTEM
FUEL TANK
FUEL PUMPS

1972 EPA EMISSIONS
GRAMS/MILE

HC	-	0.56
CO	-	5.3
NO_x	-	1.1

FIGURE 3.5.5

SECTION 4

EMISSION CONTROL SYSTEM COSTS

This section has been added to address the cost of emission control systems in greater detail than in previous years. The discussion in this section has been limited to the conventional engine. The cost of promising alternatives to the conventional engine are covered in the EPA/DOT 120 day study report*. The alternative engines generally have higher first cost for a given emission level than those engines discussed here.

4.1 Sticker Price Increases in Perspective

There are many costs associated with controlling emissions from automobiles including:

1. First cost (sticker price increase)
2. Operating cost (e.g. fuel economy)
3. Maintenance cost
4. Investment cost
5. Reduced cost of plant, animal, and human health damage due to the improved air quality possible with various emission control systems.

This section addreses only first cost in any detail. This section, therefore, contains inadequate information for a cost/benefit analysis of any emission standards. A fixed emission level system with higher first cost can produce lower total cost to the customer due to the reduced maintenance and improved fuel economy which may be possible with its use.

In the case of the 1975 Federal Interim standards, the report team estimates GM could have met the standards for $80 less first cost per car than they actually did, by eliminating the catalyst and calibrating for lower engine-out emissions. A decision to do this would have cost the customer about $500 more over 50,000 miles of vehicle life for increased fuel costs.

---

* Reference 7

Investment costs associated with the production of various emission control systems were not specifically studied by the report team, and little data was supplied on this issue in the manufacturers' status reports. No evidence was uncovered which is at odds with the NAS conclusion that, "...the somewhat higher level of capital expenditures (required to meet '77 and '78 standards) should be no problem".

In this section the sticker price of emission control hardware will be shown on both an individual component and a system basis. It should be pointed out that the reader needs to be cautious in estimating any reductions in sticker price which might occur because of the removal of any emission control hardware which is already installed on vehicles or is planned for use in the near future. Sticker prices include amortization of the costs of research, development, and tooling. Many of these costs have already been incurred for the systems necessary to achieve current and future emission standards and the customer will pay them whether or not the control hardware is ever installed in production. Another factor is that of the profit made on emission control hardware (despite claims that might lead one to believe there is no profit in what the customer must pay for emission control). Unless a lower profit is made on each car sold without some emission controls, the estimated sticker prices of control hardware will not be eliminated just because the hardware is not sold to the customer.

An important consideration in evaluating the first cost associated a particular emission standard is that a learning process can be expected to take place. In section 4.3 the report team will estimate the impact this learning process can be expected to have in the future.

All stick prices given in this section are in terms of January, 1975 dollars and in addition to value added the costs include amortization of research, development and tooling, dealer margin and profit.

4.2 Component Costs of Emission Hardware

One major factor in the costs of emission control componentry is the source of the hardware. Manufacturers who build their own hardware can be at a distinct advantage over other manufacturers who purchase hardware from supplies. GM, for example, sells their air pump to many other manufacturers, including Ford, Chrysler, and AMC. Another important factor is the level of profit taken on emission control hardware. The most important factors affecting the cost of emission control componentry, however, may be the efficiency of the basic design used and production volume. All four of these factors are undoubtedly contributing to the differences in manufacturers' estimated component costs which are shown in table 4.2.1. The only significant discrepancy between the estimates of NAS and the report team for nominal component costs concerns the cost of electronic fuel injection.

Table 4.2.1

Emission Control Component Costs
(Jan 75 Dollars)

	NAS Estimates		Range of Most Manufacturers Estimates	Report Team Estimate
Component	73	74		
1. PCV valve	$3.50	3.	2 - 3	3
2. Evap Control	$17.00	12.	5 - 18	15
3. Transmission Controlled Spark (TCS)	$4.50	-	7 - 34	5
4. Anti-Dieseling Solenoid	$6.00	-	2 - 6	6
5. Intake air heater	$4.50	-	5 - 12	5
6. OSAC spark control	$1.00	-	6	5
7. Hardened valve seats	$2.00	-	2	2
8. Port EGR	$11.50	15.	14 - 61	20
9. Air system	$52.50	35.	25 -	40
10. PEGR	$36.50	23.	35 -	40
11. QHI manifold	$6.00	-	-	10
12. Electric choke	$6.00	-	4 - 9	6
13. HEI	$11.50	-	27 - 116	30
14. Timing & other control modulation valves	$3.50	-	2 - 33	5
15. OX catalyst	$66.50	80 Pellet 61 Mono	36 - 300	80 Pellet 50 Big Monolith
16. NOx catalyst	$45.00	86 Pellet 78 Mono	75 - 178	60 Each
17. Misc. mods thru '74	$19.50	-	30 - 70	20
18. EFI	$53.00	120	250 - 556	250
19. O_2 Sensor	-	4	20 - 130	20
20. 3-way catalysts	-	97	175 - 220	100
21. Thermal Reactor	-	-	70 - 140	100
22. Improved Exhaust System	-	-	30 - 40	30
23. QA and other tests	-	-	5 - 39	10
24. Ox Pellet cat chg.	-	-	29 - 77	70
25. Mono cat chg.	-	-	- 178	150
26. EFE	-	-	10 - 15	15
27. Start catalyst	-	-	- -	50

4.3 Cost of Emission Control Systems

The system cost associated with any particular emission standard depends on the individual components used to make up the system. There is some difficulty in estimating costs for a particular standard because of the several combinations of individual components capable of achieving compliance.

Table 4.3.1 shows the values of "typical" systems according to several sources. No very significant differences exist between NAS and the report team. The high "manufacturers' estimates" are generally from European manufacturers with low production volume.

Table 4.3.1

Typical First Cost of Emission Control System
(Jan 75 Dollars)

	NAS 73 Report	NAS 74 Report	Range of most Manufacturers' Estimates	Report Team Estimates
1974 Federal (3.0, 28, 3.1)	$139	84	50 - 120	100
1975 Federal (1.5, 15, 3.1)	-	159	100 - 450	200
1975 California (.9, 9., 2.0)	-	205	170 - 455	240
1977 Federal (.41, 3.4, 2.0)	-	233	315 - 700	250 - 350
1978 Federal (.41, 3.4, 0.4)	$452	378	315 - 950	450

The "typical" systems which were used to construct the report teams estimates were:

1974 Federal - PCV, Evap control, TSC, Anti-dieseling valve, Intake air heater, Port EGR, some use of AIR, modulation valves, misc. modifications.

1975 Federal - PCV, Evap control, Intake air heater, Port EGR, modulation valves, misc. modifications, oxidation catalysts, improved exhaust system materials.

1975 California - '75 Federal plus AIR

1977 Federal - '75 California plus TCS (low fuel economy) or '75 California plus PEGR, EFE, and start catalysts (high fuel economy).

1978 Federal - '77 Federal plus air switching and NOx catalysts.

Table 4.3.2 considers other systems in addition to the "typical" systems from table 4.3.1. In addition to the cost of meeting the various standards during the year they become applicable the report team has also estimated the "essential" cost of meeting the same standards after a period for cost optimization. At the 1974 Federal emission standards most cars could have gotten by with about an $80 expenditure over uncontrolled cars. To meet the standards with better economy, however, it would have been necessary to increase system cost somewhat, for example, by using partial thermal reactors to eliminate the need for spark retard to control HC emissions. Given sufficient lead time to develop new technology and to amortize costs, it is the opinion of the report team that lean carburetion systems such as Dresser's could allow achievement of the '74 standards with only a $20 cost and excellent fuel economy.

At the 1975 Federal levels most cars could have certified with the use of unleaded fuel and more spark retard than was used on the 1974 models. Such a system would have cost about $120. To achieve good economy at the 1975 Federal levels it is desirable to use an oxidation catalyst system (probably without AIR) with its $200 first cost. Eventually Dresser type induction systems should be capable of achieving these standards without air pumps, EGR, or other devices. To maintain optimized fuel economy at these levels, it may be necessary to use high volume exhaust manifolds which would have a minimal cost increase over conventional manifolds.

Table 4.3.2

First Cost of Emission Control Systems

	1st Year		"Eventual"	
Applicable Standard	Best Economy	Minimum Cost	Best Economy	Minimum Cost
1974 Federal 3.0, 28., 3.1	150	80	20	20
1975 Federal 1.5, 15., 3.1	200	120	40	20
1975 California .9, 9., 2.0	250	200	90	20
1977 Federal .41, 3.4, 2.0	340	250	150	90
1978 Federal .41, 3.4, 0.4	450	350	?	300

At the 1975 California levels the oxidation catalysts or lean thermal reactor system would be necessary at a cost of about $200. The addition of AIR and proportional EGR to the catalyst system should allow the .9, 9, 2.0 levels to be met with excellent fuel economy. In the longer term the Dresser-type of induction system should meet these levels with only spark retard. Eliminating spark retard for improved economy, the standards could still be met with the use of partial thermal reactors for a total system cost of about $90.

To achieve the 1977 Federal emission standards (.41, 3.4, 2.0) the AIR/catalyst system with spark retard will be needed for most cars. Avoidance of fuel penalties will probably necessitate the use of improved quick-heat intake systems and start catalysts with a total system cost of about $350. Dresser-type systems with partial thermal reactors and spark retard could eventually achieve these standards ($90 cost) but the use of Dresser with an oxidation catalyst system and high volume exhaust manifolds makes the standards feasible with no fuel economy loss and a $150 first cost.

At the 1978 Federal Standards, dual catalysts will be required both in 1978 and in the longer term (assuming conventional engine technology). Such a system will cost $350 and will probably require some spark retard. The addition of technology sufficient to eliminate the need for spark retard is estimated at about a $100 cost penalty.

The system choices discussed above are the report team's estimate of what can occur given the incentive on the part of the industry to meet future standards with low first cost or high fuel economy. As discussed earlier in this report, however, the system choices are made after considering many different aspects of automobile marketing strategy. Under the current regulatory/economic/consumer demand situation, there is no guarantee that systems with the potential for combined low emissions, low cost, and high fuel economy will be developed and mass produced.

SECTION 5

UNREGULATED EMISSIONS

Unregulated emissions include sulfates, hydrogen sulfide, platinum, palladium, polycyclic organic matter (POMs, a type of hydrocarbon), aldehydes, reactive organic compounds, and particulate emissions. Since almost all of the information submitted to EPA was on sulfates, most of this chapter discusses sulfates with mention of the other unregulated emissions being limited to a summary.

Hydrogen sulfide can be emitted from catalyst vehicles when they operate under rich conditions. Hydrogen sulfide has a characteristic "rotten egg" odor at levels far below those associated with adverse health effects. Scattered reports have been received of hydrogen sulfide odors from in-use 1975 catalyst vehicles. EPA is still assessing the magnitude of this problem and what action can be taken to correct it. Preliminary indications are that the H_2S - emitting vehicles have improperly adjusted or defective emission control hardware which results in overly rich conditions into the catalyst.

There have been many attempts to quantify noble metal emissions including platinum and palladium from catalyst equipped vehicles. To date, noble metal emissions have been measured in only a few very isolated cases. Work to measure these emissions and to determine the health effects of noble metals is continuing.

Regarding aldehydes, reactive organic compounds, and POMs, some work has been done in the past year indicating that emissions of these compounds greatly decrease with the use of catalysts. Apparently, the catalyst preferentially oxidizes the more reactive hydrocarbon compounds in preference to less reactive ones. In fact, methane, a totally unreactive hydrocarbon, now comprises a greater percentage (approximately 15 percent) of exhaust hydrocarbons compared with pre-catalyst vehicles (which have about 10 percent methane in the exhaust). Since methane is not included in the ambient air quality standard, EPA is considering amending the automotive hydrocarbon standard to exclude methane. The decrease of these reactive emissions with the use of catalysts is a positive health benefit.

Total particulate emissions of catalyst car burning unleaded fuel are substantially lower than pre-catalyst cars which burned leaded fuel. The lower particulate emissions are due to the lack of lead compounds in the exhaust. Tests to date on oxidation catalyst vehicles have not shown any serious problem due to catalyst attrition products (i.e. small particles of the catalyst itself) increasing particulate emissions. Some reduction catalysts which would be required to meet a 0.4 gpm NOx standard, have shown catalyst attrition. This phenomenon has occurred with the Gould reduction catalyst which emitted nickel compounds in preliminary EPA tests. The seriousness of this problem is not known yet for the Gould catalyst, but will be evaluated in future programs. At any rate, catalyst attrition products have not been found to be a problem with oxidation catalysts.

However, it has been found that catalyst cars have increased particulate emissions, compared with non-catalyst cars burning unleaded fuel. This increase is due to formation of sulfur trioxide over the catalyst with subsequent combination of the SO_3 with water to form condensed sulfuric acid. The SO_3 is formed by oxidation of SO_2 which is formed in the engine from combustion of the fuel sulfur. The sulfuric acid or sulfate, as it will be referred to, is considered a particulate and is emitted only from catalyst cars. Sulfates from catalyst cars account for less than 1 percent of the total sulfates in any AQCR with the remaining 99 percent coming from photochemical oxidation of SO_2 emitted from stationary sources. However, EPA is greatly concerned about automotive sulfate emissions since they can result in high localized sulfate levels along freeways and other places. Most of the work done in the past year on unregulated emissions has been on sulfates.

The first major conclusion that can be made from this work is that non-catalyst cars emit only trace quantities of sulfates with almost all of the fuel sulfur being emitted as SO_2. This finding is in contrast to some early work reported last year showing non-catalyst cars to emit substantial quantities of sulfate.

Extensive work has been done in the past year to determine emission factors for both pelleted and monolith catalyst cars. The first finding is that pelleted catalyst vehicles emit less sulfate under the FTP than monolith catalyst vehicles. This lower emission rate is due to a storage reaction of sulfates and the alumina. This interaction occurs at low catalyst temperatures (which occur at lower speeds) and is reversible at higher catalyst temperatures where sulfates are released. Since monolith catalysts have only small quantities of alumina compared with pelleted catalysts, the storage phenomenon is much less pronounced for monolith catalysts. The sulfates stored on the pelleted catalyst under low speed conditions are later released in the transition from low to high speed driving, and makes measurement of sulfate emissions from under low speed conditions very difficult. After the transition period from low to high speed driving, pelleted and monolith catalyst vehicles emit essentially the same quantities of sulfate at higher speeds (60 mph). Typical emission factors are given in the following table:

Best Estimate Sulfate Emission Factors*
(mg/mi)

	Pelleted Catalyst	Monolith Catalyst
Urban Driving (FTP)	10-15	30
Highway Cruise (60 mph)	50-60	50-60
Urban-to-highway Cruise Transition	100-300	50-60

*mg/mi assuming 0.03 percent by weight sulfur fuel (the current national average). Also, assumes utilization of air injection. Values for vehicles without air injection would be lower.

These numbers are best engineering judgements based on the data discussed in this chapter. It is thought that, in accounting for the storage phenomenon, pelleted and monolith catalysts have essentially identical sulfate emissions over their lifetime. In certain areas such as Southern California with fuel above the 0.03 percent national average sulfur content, sulfate emissions would be higher than those shown above. Also, these estimates are based on full size 1975 cars and do not consider the improved fuel economy of smaller cars which would lower sulfate emissions. Any future improvements in fuel economy over that of 1975 cars will result in lower sulfate emissions.

Various parameters on catalyst cars such as air injection rate, noble metal loading, residence time, and catalyst temperature can be optimized for maximum control of both sulfates and regulated gaseous emissions (HC and CO). Preliminary work done by GM and Exxon (under an EPA contract) suggests that control of air injection rate may be the most promising of these areas. While limiting the air injection rate decreases sulfates significantly, HC and CO emissions are increased. Work is continuing in this area.

Chemical traps installed after the catalyst also have the potential of controlling sulfates. The automobile companies are doing almost no work examining vehicle sulfate traps. Most of the work being done on sulfate traps is through an EPA contract with Exxon. A calcium oxide trap has been tested for 25,000 miles and removed over 90 percent of the sulfate. By then, however, a serious back pressure had developed across the trap. While work is continuing in this area, not enough data are available to determine if this is a feasible control technique.

EPA is examining whether fuel desulfurization is technically and economically feasible. Results on this work to date show the following:

1. Gasoline desulfurization is technically feasible. A $2 to $4 billion capital investment will be required to lower unleaded gasoline from 0.03% to sulfur levels of 0.006 - 0.01%. This cost is equivalent to about 1¢/gallon.

2. About 3-5 years would be needed for equipment installation.

An additional potential cost implication in the fuel desulfurization issue is the fact that sulfur-free fuel may allow the use of base metal catalysts. These catalyst types are much cheaper than the noble metal ones used now and are not currently used because they suffered from sulfur poisoning in early development tests.

Sulfate emissions have been measured for a limited number of advanced catalyst systems and alternate engines. While definitive sulfate emission factors have not been obtained yet, it is our judgement that sulfate emissions from systems with a reduction and oxidation catalyst will be no higher than those from oxidation catalysts. Preliminary in-house EPA work shows very low sulfate emissions from a three-way catalyst designed for simultaneous HC, CO, and NOx control. These low sulfate emissions are probably the result of close oxygen control required for operation of the catalyst. Finally, EPA work shows low sulfate emissions from advanced alternative engines including the stratified charge and LDV Diesel. However, if the higher sulfur content of Diesel fuel is considered, the Diesel can possibly emit sulfates at rates approaching the catalyst vehicle.

SECTION 6

INDUSTRY STATUS

6.1 Industry Status - 1976 Model Year

Since the standards are the same for model year 1976 as they are for model year 1975, more emission control is not required. Therefore, all new systems do not have to be developed and certified, as was the case for the model year 1975. Most manufacturers will carry over their systems from 1975 to 1976. The process of carry over is the use of the certification from one model year for the next model year, which is permitted if the standards and test procedures are the same, as is the case for model year 1975 and 1976.

This does not mean that there will be no activity in the emission control area, however. It appears that the practice of making running changes to vehicles covered by existing certificates will increase greatly. Manufacturers appear to prefer this course of action, since in most cases they do not have to run durability cars if a running change is approved. The report team estimates that running changes will be the primary area of activity in the emission control certification effort for model year 1976 for most manufacturers, and that EPA will have to increase its efforts in this area to ensure that the effectiveness of the certification procedures are not compromised.

In summary, the report team expects that model year 1976 will be one that will involve a process of refinement of the current year 1975 systems.

6.2 Industry Status - 1977 Model Year

6.2.1 Systems to be Used - 1977 Model Year

There are two basic approaches that the manufacturers can take toward meeting the 1977 standards of 0.41 HC, 3.4 CO, 2.0 NOx. The first approach is the use of recalibrated systems like those used in 1975 to meet the 1975 California standards of 0.9 HC, 9.0 CO, 2.0 NOx. The additional HC and CO control required could be achieved for example, by increased spark retard for HC control; and leaner overall carburetion calibrations, shorter choke times, and increased air injection rates; for CO control. While certainly a low-cost approach (for the manufacturer) the approach of recalibrating a 1975 California package is expected by the report team to result in a fuel economy penalty compared to the 1975 California package because we estimate that the increased spark retard will offset any improvements due to the extra enleanment.

The second approach is to employ improved oxidation catalyst systems, based on the 1975 California package. HC is going to be the major problem, although improved control of both HC and CO are needed to meet the 0.41 HC, 3.4 CO, 2.0 NO_x standards, compared to the 1975 California standards. HC is going to be the major problem for two reasons: (a) current oxidation catalysts have lower high mileage conversion efficiencies for HC than for CO. (b) The technique of the use of spark retard for HC control is now considered much less desirable than it once was, due to the current increased importance being placed on fuel economy as a design goal. Indeed, today the desire is to advance the spark toward the optimum, as much as possible.

The report team uses the term AOC (for Advanced Oxidation Catalyst) to describe the systems that employ more advanced emission control that could be employed to meet the 0.41 HC, 3.4 CO, 2.0 NO_x standards without exhibiting some of the unattractive characteristics of a recalibrated 1975 California package.

There are three basic areas in which improved control can be obtained. These areas are:

1. Improvements to the air/fuel mixture process, mixture distribution, transient fuel metering control, and the warm-up mixture requirements. These are improvements to the air/fuel mixture before combustion takes place in the engine.

2. Improvements to the design of the combustion chamber, the in-cylinder air/fuel motion and the ignition system. These are improvements to the combustion process in the engine.

3. Improvements to the systems that treat the exhaust after combustion takes place in the engine.

A more detailed description of the types of system that could achieve the desired results was provided in Section 3.

Most manufacturers are aware of the capabilities of more advanced control technology, and some are actively working on improved systems. However, most manufacturers, in the opinion of the report team, are working on improved oxidation catalyst systems at a relatively low level currently. One possible reason for this could be the current reduced level of employment in the industry in general and possibly in the emission control development area also, although we have no data on current employment levels in this area. Another reason could be that the industry is waiting to see what will happen during the upcoming EPA Suspension Hearings, and also awaiting to see how their proposals to the Congress and the Administration for a moratorium on future standards are received.

Not all of the system improvements discussed in Section 3 will be required on all 1977 models. The choice of which systems will be used will depend on the specific engine family - emission control system - vehicle combination and its performance with respect to the 0.41 HC, 3.4 CO, 2.0 NO_x level. More importantly, the use of advanced systems for model year 1977 will depend greatly on the emphasis that any given manufacturer places on improving or maintaining his fuel economy performance demonstrated in 1975.

The report team estimates that the improvements generally to be in use for 1977 will include improved catalysts, improved air injection systems and better quick warm-up devices. However, this is dependent on the assumption that the manufacturers now think that they will have to meet 0.41 HC, 3.4 CO, 2.0 NO_x in 1977, an assumption considered questionable by the report team, since most manufacturers have adopted a "wait and see" attitude.

6.2.2 Durability Testing Programs - 1977 Model Year

Two kinds of durability efforts are planned or underway currently that could be interpreted as influencing the model year 1977 systems. The first type of durability testing is an attempt by manufacturers who used the crutch of catalyst replacement to pass certification in 1975. These manufacturers will be trying to go 50,000 miles for 1976, with improved catalysts and/or more confidence in the durability performance of their systems. The data from such testing could be used as development data for model year 1977. The second type of durability testing contemplated is early model year 1977 durability testing. This is planned by some domestic manufacturers for very early in calendar year 1975. While this early durability testing may give more time for the manufacturers to make more extensive running changes before model year 1977, the report team considers it likely that the early certification durability attempts are too early to incorporate much in the way of improved technology. A manufacturer may be reluctant to try to certify a more sophisticated package if he is successful at getting through certification durability with a simpler system, even if he sacrifices fuel economy potential, in the opinion of the report team.

In general, extensive fleets of development durability vehicles with advanced systems are not now on the road, reflecting the same "wait and see" attitude discussed above in the discussion of Systems to be Used.

6.2.3 Progress and Problem Areas - 1977 Model Year

Progress has been made in the industry in general since a year ago, primarily in the area of oxidation catalyst system testing and development. Investigation of the engine calibration flexibility inherent with the catalyst approach has been a subject of increased activity. Advanced systems have been tested with a low level of effort with some encouraging low mileage results.

A problem area is the lack of extensive development and durability testing mentioned above. The major problem at the 1977 level, in the opinion of the report team, is system selection for 1977. The manufacturers must be considering the answers to many difficult questions at this point in time. Answers to questions such as: Am I going to have to meet the standards? Is one system cheaper than the others? Do the more expensive systems have greater fuel economy potential? By how much? Will people buy the more expensive vehicle if it has better fuel economy? All must be resolved by a manufacturer before he can commit to a firm development/testing/certification effort for model year 1977.

6.3 Industry Status - 1978 Model Year

6.3.1 Systems to be Used - 1978 Model Year

Two basic types of systems are generally under consideration for model year 1978. They are the dual catalyst system and the 3-way catalyst system. The dual catalyst system, which uses separate catalysts for NO_x and HC/CO control has been under development longer than has the 3-way catalyst which uses a single bed to simultaneously control HC, CO, and NO_x. The major problem with the dual catalyst system is expected by the report team to be HC, not NO_x since the calibration technique tends to increase the engine-out HC emissions, and more sophisticated HC control techniques will have to be used. It must be pointed out that no such development work was reported by the manufacturers.

The second type of system under consideration for NO_x levels below 2.0, the 3-way catalyst system, has recieved increased development and testing in the last year or so. In fact it now appears to be the only system under active development at low NOx levels. Many manufacturers are using the typical 3-way approach, a single bed catalyst with feedback control of engine air/fuel ratio but there are some variations being investigated by some manufacturers. The first variation is the system named 3-way + OX Cat by the report team. This system employs a 3-way catalyst calibrated to bias the conversion to favor NO_x removal (although HC and CO are still converted) and uses an oxidation catalyst downstream to convert any excess HC and CO. This system is much like a dual catalyst system. The second variation on the 3-way approach is in the way the correct air/fuel ratio mixture is provided to the catalyst. Most 3-way systems use an oxygen sensor in the exhaust stream to feed back a signal that is used to control the fuel injection or carburetor metering to achieve the correct engine out air/fuel ratio for efficient 3-way catalyst operation. Since the expense of a fuel injection system is a square pill for much of the industry to swallow, some manufacturers are investigating the use of feedback-controlled air injection to provide the correct air/fuel mixture to the catalyst. This is considered a promising development by the report team since it may be possible to achieve good 3-way conversion at lower cost.

Most manufacturers that are developing the 3-way catalyst approach have been able to attain the 0.41 HC, 3.4 CO, 0.4 NOx levels at low mileage on developmental vehicles.

Low-mileage and optimization testing of dual catalyst systems have not received much attention in the past year or so, a reflection of the generally low level of effort in the area of systems targeted toward 0.41 HC, 3.4 CO, 0.4 NOx. This is somewhat disappointing because the developments reported by Gould* in the last year or so represent the most significant advance to date in the NOx catalyst area, in the opinion of the report team. This promising system, which uses an oxygen removal catalyst (an oxygen getter) upstream of the NOx catalyst to improve its durability performance, has shown good low mileage activity, typically 75 to 80 percent net NOx conversion. This type of system, used in conjunction with the engine calibration techniques discussed by Gumbleton** could result in a dual catalyst system with good fuel economy and low NOx emissions, since the catalyst efficiency is high and the engine calibrations yield good fuel economy with low (1.1 to 1.3 NOx) engine-out emissions.

6.3.2 Durability Testing Programs - Model Year 1978

Durability testing of systems targeted toward the 0.41 HC, 3.4 CO, 0.4 NOx level has virtually ceased for dual catalyst systems. Many manufacturers have run no cars in the past year or have run just one or two. The most promising dual catalyst durability results have been reported by Gould with their latest system, with 50,000 equivalent miles on a dynamometer and 25,000 of AMA durability, both tests showing good net NOx conversion efficiency. With the assumption that the NOx conversion efficiency can be maintained at 75 percent at 50,000 miles, (Gould's tests show over 80 percent at 25,000 miles and relatively low degradation in efficiency) an estimate of the capability of such a system at 50,000 miles, calibrated for low engine-out NOx can be made. With 75 percent efficiency and a 1.2 NOx input, the resulting emissions would be 0.3 NOx, a level enough below the 0.4 standard to give reasonable chances to certify. Of course as mentioned above, HC may be a problem and the capability of such a system will not be known until such a system is built up and tested. However, it does appear now that meeting 0.4 NOx is now not an unreasonable proposition.

---

* "Durability Experience with Metallic NOx Catalysts", SAE Paper 741081 by R. J. Fedor et.al. presented at the Automobile Engineering Meeting, Toronto, Canada, October 21-25, 1974.

** "Optimizing Engine Parameters with Exhaust Gas Recirculation", SAE Paper 740104 by James J. Gumbleton, et.al. presented at the Automotive Engineering Congress, Detroit, Michigan, February 25-March 1, 1974.

Durability testing with 3-way catalyst systems has been more extensive, but the results to date generally have not been encouraging. One of the durability problems with 3-way systems is that the percent loss in efficiency in both HC/CO and NOx. Separately, efficiencies may remain high but at different air/fuel ratios, the high HC/CO conversion at lean air/fuel ratio and the high NOx conversion at a slightly rich air/fuel ratio. The feedback control system continues to hold the input air/fuel ratio between the peak efficiency points, so at high mileage the conversion efficiency for both HC/CO and NOx is poor. The report team considers this 3-way approach to be less attractive than the dual catalyst approach at the 0.4 NOx level, because of the durability problems, and the compromise between oxidation and reduction performance which is made.

6.3.3 Progress and Problem Areas - 1978 Model Year

The major progress toward meeting 0.4 NOx in the past year has been achieved by Gould with their dual catalyst system. No automobile manufacturer has done as well, in the opinion of the report team.

Progress has been made in the 3-way catalyst area also. Improved catalysts are now being developed and tested. This area of improved 3-way catalysts must progress much more than it has to date to have a chance at meeting 0.4 NOx, in the opinion of the report team. While currently the best 3-way system might have a chance in a light weight vehicle, for vehicles more typical of heavy domestic automobiles the efficiencies are just not good enough at high mileage. Actually, the report team feels that the 3-way catalyst development work is not targeted at a 0.4 NOx target at all, but most manufacturers are developing these systems for a NOx standard which they are guessing will be about 1.0 NOx.

As pointed out in last year's report, the report team's analysis of the development programs actually targeted toward to 0.4 NOx leads us to conclude that manufacturers must believe that they will not have to meet 0.4 NOx in 1978, if ever. Development and durability programs are at such a low level of effort that it is doubtful that the manufacturers can get going in time to meet the levels still required for 1978, even though the report team feels that the 0.41 HC, 3.4 CO, 0.4 NOx levels can be met, from a technical standpoint.

SECTION 7

INDIVIDUAL MANUFACTURER'S REVIEWS

7.1.1 American Motors

7.1.1.1 Systems to be Used

Systems to be Used - 1976 Model Year

The 1976 American Motors Corporation (AMC) systems will be basically the same as those of 1975. Exhaust backpressure modulated EGR and electric assist chokes will be used on all models in 1976. Transmission-controlled spark delay valves will be completely eliminated. Six cylinder models will have a new stainless steel "hot spot" in the inlet manifold and a new combustion chamber to improve detonation control and allow more spark advance. All catalysts used by AMC are 160 CID, pellet-type catalysts from AC Spark Plug. Pellets are spherical and are loaded with about .05 troy ounces of noble metal in the proportion of 71% platinum and 29% palladium. The 360-4V and 401-4V dual exhaust equipped vehicles utilize one catalyst on each side of their exhaust systems.

Systems durability data indicate that 1975 FTP fuel economy of the 232 six cylinder models may be significantly improved over the comparable 1975 models; however eight cylinder models demonstrated insignificant changes in fuel economy. This is primarily due to spark advance improvements on the six cylinder which were made possible by the improved combustion chamber.

Systems to be Used - 1977 Model Year

The 1977 AMC system will include AIR, backpressure EGR, transmission controlled spark (TCS) and the pellet type oxidation catalyst. Also monolithic "start" catalysts near the exhaust manifold will be used on all models. Six cylinder models will use one "start" catalyst and eight cylinder models will use one on each bank. The new combustion chamber design will be continued on the six cylinder models and introduced on eight cylinder models. New pellet catalysts are being prepared for AMC evaluation by AC Spark Plug.

AMC is investigating the use of a segmented monolithic main catalyst for 1977. Several thin catalyst "biscuits" are separated by airspaces to promote turbulent exhaust gas flow through the converter. Initial test results indicated a HC deterioration problem.

Fuel economy estimates presented by AMC indicated a 13% decrease in fuel economy over 1976 models. The report team could not varify this fuel penalty as AMC vehicles achieved the 1977 levels in only a few instances. Some of those used methanol in the fuel.

Systems to be Used - 1978 Model Year

The AMC system for the .41 HC, 3.4 CO, .4 NOx level is stated to be a dual catalyst system with backpressure EGR, switching AIR, TCS, and the improved combustion chamber. The use of the stainless steel "hot spot" will be extended to include eight cylinder models in addition to the six cylinder models. Six cylinder models will use one reduction catalyst and eight cylinder models will use two. The Gould GEM 68 reduction catalyst with an oxygen "Getter" is being prepared for testing.

AMC is developing a rich thermal reactor with Vortex Research and Development. Initial results of .48 HC, 10.2 CO, 2.62 NOx did not meet 1975 California levels. Catalysts, EGR, TCS, and the "hot spot" intake manifold were not used. This is the only so-called 1978 system tested by AMC in 1974.

According to AMC, fuel economy is reduced about 25% from 1975 Federal models, however, no data were submitted to substantiate this figure.

Other Systems

The AMC status report mentioned the assessment of rich thermal reactors for the AMC rotary engine program. No further details or data were submitted on rotary engines.

No data was presented on advanced AIR or fuel metering systems. Electronic control systems have not been utilized except for electronic ignition. No evidence of 3-way catalyst testing was reported. No improvements have been noted for the AMC bimetallic actuated heat riser. In the opinion of the report team, the inexperience of AMC with advanced emission control systems, especially advanced fuel metering systems, will cause unnecessary problems for AMC at 1978 emission levels.

Table AMC-1

1976 AMC Control Systems

Engine	AIR Drive Ratio	EGR	Number of Oxidation Catalysts
232	--	x	
232	1	x	
258	--	x	
258	1	x	
258	1	x	1
304	1.25	x	1
360-2	1.25	x	1
360-4	1.25	x	2
401-4	1.25	x	2

7.1.1.2 Durability Testing Programs

Durability Testing Program - 1976 Model Year

AMC conducted durability testing on twelve vehicles at the 1976 49-state and California emission levels. The objective of this effort was to evaluate modifications designed to improve fuel economy and driveability while maintaining compliance with the 1975/1976 standards.

Durability Testing Program - 1977 Model Year

At the .41 HC, 3.4 CO, 2.0 NOx level, AMC conducted durability testing on five cars. The cars were equipped with upgraded 1976 California systems, which for the most part amounted to recalibration of ignition, carburetion and air injection rates along with the addition of a low thermal mass monolithic converter between the exhaust manifold and the conventional underfloor pelletted converter. None of the five cars complied with .41 HC, 3.4 CO, 2.0 NOx level. One car accumulated 50,000 miles and the remainder were at approximately 25,000 miles.

Durability Testing Program - 1978 Model Year

No durability testing was reported by AMC for NOx levels below 2.0 gm/mi.

7.1.1.3 Progress and Problem Areas

Progress and Problem Areas - 1976 Model Year

AMC has made progress in the area of system selection for 1976. The 1976 systems will generally be improved over the 1975 systems, especially for the 6-cylinder models, AMC's biggest sellers. Improvements to the EGR systems, (proportional), spark modulation systems (TCS eliminated), induction system (new hot spot manifolds and electric assist chokes), and a revised combustion chamber allowing more spark advance will all tend to improve the entire control system over the 1975 package. A problem for AMC for 1976 is that the V-8 engines will apparently not get all of the improvements that the six cylinder engine gets, probably because the V-8's are not as important a part of AMC's sales picture as are the sixes, in the opinion of the report team.

Progress and Problems - 1977 Model Year

Because AMC's underfloor converters take a relatively long time to light off, they are developing a system that employes an additional low thermal inertia oxidation catalyst upstream of the main catalyst. This configuration has many of the properties of a "start catalyst" system. The term "start catalyst" as used by the report team, refers to a catalyst which is used to improve cold-start HC and CO emissions, but is hot capable of doing the whole HC/CO cleanup job. The catalyst may or may not remain on-stream all of the time.

Table AMC-2

1975 FTP Fuel Economy of Various AMC Models

Engine	Trans	IW	1974	1975 Federal	% Change from 1974	1975 Calif.	% Change from 1974	1976	% Change from 1974	% Change from 1975 Fed.
232-1	M3	3500	--	18.0	--	13.8	--	20.9	--	+16
302-4	A3	4500	12.3	13.0	+6	12.7	+3	13.2	+7	+2
360-2	A3	4500	10.8	12.6	+17	11.8	+9	12.4	+15	-2

AMC's major problem at the 0.41 HC, 3.4 CO, 2.0 NOx level is the lack of a definitive durability testing program. The major durability test reported was one that, besides emission control system deterioration, included several other tests in addition. The test involved operation on Ohio interstate highways (not AMA) for mileage accumulation, the evaluation of medium and low ash oils, an investigation of the effects of a 10 percent methanol fuel in additional to commercial unleaded Sohio Cetrol fuel, evaluation of a carburetor detergent versus dispersant plus solvent oil, and the evaluation of two different air injection configurations. This development durability test should yield much information to AMC, but it really does not indicate AMC's capability to certify at 0.41 HC, 3.4 CO, 2.0 NOx, because so many of the test conditions are different than the ones used for official certification. The report team considers it likely that AMC will use this test to generate knowledge that will be useful in building up a 1977 pre-certification fleet in the future.

Progress and Problems - 1978 Model Year

AMC has had a low level of effort on systems targeted toward the 0.4 NOx level for a few years now, so AMC's indication that they were going to evaluate a Gould GEM 68 catalyst system with oxygen getter was a hopeful sign. Apparently, AMC has waited for a system that they feel has some potential for success at the 0.4 NOx level. The Gould system is the best one around at this point in time in the opinion of the report team. AMC reported no data from this system, because it has not been tested yet. The report team considers AMC's interest in this advanced dual catalyst system to be encouraging since many other manufacturers seem to be unaware of this system and its potential.

AMC's major problems at the 0.4 NOx level is lack of testing. No data on any 0.4 NOx target vehicles was reported.

7.1.2. Chrysler

7.1.2.1. Systems to be Used

Systems to be Used - 1976 Model Year

Chrysler Corporation will be recertifying virtually their entire line in 1976 in an effort to improve fuel economy and reduce costs over the 1975 models.

Chrysler systems for 1976 are described in table Chrysler-1.

Table Chrysler-1

1976 Chrysler Control Systems

		System Includes				
	Family	Ported EGR	Venturi Vacuum Amplified EGR	AIR	Aspirator	Oxidation Catalyst*
1	FD-225-1-35		x			.02 (All Pt)
1	FD-225-1-55		x			.04 (All Pt)
1	FD-318-2-35	x				.02 (All Pt)
1	FD-318-2-P		x	x		
1	FD-318-2-55	x				.04 (All Pt)
1	FD-360-2-55		x			.04 (All Pt)
2	FA-360-4-P		x	x		
1	FD-400-2-55		x			.04 (All Pt)
2	FB-400-4-P		x	x		
1	FC-440-4ST-5L		x			.06 (All Pt)
2	FB-440-4HP-75		x			.08 (70 Pt/30 Pd)
1	CD-225-1-P5S		x	x		.04 (All Pt)
1	CD-225-1-A55		x		x	.04 (All Pt)
1	CD-318-2-P5S		x	x		.04 (All Pt)
1	CD-360-4-P55		x	x		.04 (All Pt)
1	CD-400-4-P55		x	x		.04 (All Pt)
1	CD-440-4ST-P5L		x	x		.06 (All Pt)
2	CD-440-4HP-P75**		x	x		.08 (70 Pt/30 Pd)

* troy ounces of noble metal

** includes catalyst protection device

The 49-State systems (families with identification codes starting with F) are of two major components and consist of either EGR and AIR or EGR and oxidation catalysts. The older ported EGR is still used on the 49-State 318 catalyst vehicles, and the improved venturi vacuum amplified EGR is used on all others.

All California systems (code starts with C) consist of AIR (or an aspirator), EGR, and oxidation catalysts. The aspirator used on one of the California 225 CID engines is used to replace AIR. The aspirator principle is to induce air into the exhaust manifold through a one way valve during periods of low exhaust manifold pressure created by the pulsating engine exhaust. In Chrysler testing it has not been as effective as air injection for HC and CO oxidation or fuel economy optimization.

All Chrysler catalysts are made by Universal Oil Products (UOP) and are monoliths. Catalyst loadings are stated in Table Chrysler-1. The catalyst protection device on the California 440 engine relocates the throttle stop positioner to provide more intake air flow during decelerations which begin at engine speeds above 2200 rpm.

All 1976 systems also include orifice spark advance control (OSAC), coolant controlled EGR (CCEGR), and electrically assisted chokes. The OSAC is a spark delay valve. CCEGR prevents EGR system operation while the engine is cold, and the electrically assisted chokes provide more consistent choke operation. Other minor systems that are frequently used are heated intake air, thermostatic ignition distributor vacuum control (TIDC), an EGR timer, and coolant controlled idle enrichment (CCIE). TIDC increases the vacuum spark advance when the coolant temperature goes above 225°F. This is to reduce the engine's heat rejection and prevent cooling system boil over. The EGR timer provides 35 seconds of engine operation without EGR after all engine starts. CCIE supplements the choke and provides more accurate cold idle fuel management.

The initial cost of 1976 Chrysler vehicles is expected to be an average of nineteen dollars cheaper than the 1975 models. Fuel economy of the 1975 models is compared to 1974 models in table Chrysler-8. Though no comparative data was presented, Chrysler estimated that fuel economy of the 1976 models will be improved 0-10% over 1975 for an overall 3% improvement. Catalyst replacement cost at 50,000 miles is expected to be about $95.

Systems to be Used - 1977 Model Year

The first choice Chrysler system to achieve the .41 HC, 3.4 CO, 2.0 NOx standard is the 1976 California system of AIR, venturi vacuum amplified EGR, and oxidation catalysts plus a smaller, rapid light-off "start catalyst" near the exhaust manifold. On V-8 engines there will be a start catalyst on only one bank with a power heat valve on the other bank to provide maximum exhaust flow through the start catalyst during warm up. Six cylinder models will not need the valve system. Other systems still being considered include dual start catalysts on V-8 models, improved main catalysts to eliminate the start catalyst, a lean burn-oxidation catalyst system with electronic spark advance on the six cylinder and small V-8 models, and a dual catalyst system to eliminate EGR and OSAC NOx controls. The report team feels that the dual catalyst approach is unnecessary at the 2.0 NOx level and that greater fuel economy benefits could be achieved with improved EGR, EFE, and fuel metering systems.

Initial cost of the 1977 Chrysler vehicle is expected to increase $185 over 1975. Catalyst replacement cost at 50,000 miles is estimated at $180 and includes replacement of both the start and main catalysts. Chrysler estimates a 12% fuel economy loss for 1977 over the 1975 49-State systems. This fuel penalty estimate appears unlikely to the report team as Chrysler data indicates 18-29% improvements in fuel economy over similar 1974 models and improved or equivalent fuel economy over 1975 for all complete or incomplete systems achieving the 1977 levels as shown in table Chrysler-8.

Table Chrysler-2

Low Mileage 1977 System Results

Engine	System	HC	CO	NOx	FE
225-A3	lean burn, ox. cat. electronic spark advance	.33	2.0	2.1	16.6
318	NOx cat. retard	.32	2.9	1.1	12.1
318	NOx cat.	.46	3.3	1.6	13.0
225-M3	1977 1st Choice	.26	1.9	1.54	18.1
400-4-A3	1977 1st Choice	.20	1.4	1.26	11.9
360	NOx Cat.	.66	4.37	1.52	11.93
318 B body	76 C4	.34	3.20	1.91	12.41
318 B body	76 CA	.33	3.26	1.75	12.73
Above at 15,000 miles		.32	1.80	1.74	13.17
440 C body		.26	2.60	1.75	9.44
Above at 10,000 miles		.38	1.29	1.61	9.70
360-4	76 CA+100-0 Ox. Cat.	.18	2.0	1.85	

The following table indicates the results obtained with a start catalyst.

Table Chrysler-3

Start Catalyst Evaluation

Vehicle 1 - Chrysler Newport, 400-4V, A3, venturi vacuum amplified EGR, AIR, Chrysler oxidation catalyst, dual Chrysler start catalysts.

	HC	CO	NOx	Fuel Economy
Without Start Catalyst	.42	2.21	1.26	11.6
With Start Catalysts	.20	1.20	1.28	12.3
(3 tests)	.23	1.68	1.19	11.8
	.17	1,29	1,32	11,6
Ratio: With Start Catalysts Without Start Catalysts	.47	.62	1.00	10.2

Systems to be Used - 1978 Model Year

The Chrysler system for .41 HC, 3.4 CO, .4 NOx is a dual catalyst system with switching AIR, EGR, OSAC, and spark retard. Both noble metal and base metal NOx catalysts are still under consideration. Also the Questor Reverter System with rich thermal reactors, heated AIR, and NOx catalysts is slated to begin durability testing on a single car.

Chrysler 1975 FTP testing has verified the capability of these systems as in tables Chrysler-4 and Chrysler-5; however, the Chrysler testing has been limited to only a few cars without optimum AIR, EFE, fuel metering, or EGR (no EGR in some cases). Chrysler development in most of these areas has not progressed much in the past year. This will handicap Chrysler durability efforts at this control level by placing greater burdens on the Chrysler catalysts. Furthermore fuel economy cannot be optimized using the control systems tested by Chrysler at the 1978 levels.

No cost estimates were submitted for the 1978 model year systems.

Table Chrysler-4

360-2V, A3, 5000 lb. Dual Catalyst Vehicle

HC	CO	NOx	Fuel Economy
.40	2.85	.21	11.8
.35	2.55	.28	11.3
.26	1.68	.38	11.8
.25	2.56	.38	11.2
.26	2.6	.36	11.2
.25	1.36	.30	10.8

Table Chrysler-5

360-2V, A3 Questor Vehicle

IW	HC	CO	NOx	Fuel Economy
4500	.39	3.14	.34	10.1
4500	.20	2.18	.38	11.0
5000	.31	2.84	.32	9.4
5000	.15	1.94	.33	9.7

Other Systems

Development is continuing on standard venturi, small venturi, variable venturi, altitude and temperature compensated, and concentric - staged dual carburetors for improved emissions control system performance for 1976 and 1977 Federal standards as well as for 1978, according to Chrysler.

The Bendix electronic fuel injection system is to be installed on two Chrysler vehicles soon in an attempt to improve fuel management for 1978. A Chrysler electronic fuel injection system also is being developed. This system in conjunction with a Chrysler induction system produces sonic mixture velocities and has extended the lean misfire point to .052 F/A (greater than 12 A/F) according to Chrysler. Initial results show 2.0 HC, 15.0 CO, and 2.3 NOx with this system on a 440 CID Imperial. This system is eventually intended for use with oxidation and 3-Way catalysts. The report team assumes that the 3-way catalytic approach will not use the lean A/F ratio which is under investigation in the current program. Also, the report team feels that this system with an oxidation catalyst could prove to be a promising system for 1977 if development work could be hastened.

Early fuel evaporation (EFE) systems are under active development at Chrysler. The 1975 FTP results of these are presented in tables Chrysler-6 and Chrysler-7. The electric hot spot (EHS) provides electrical heating below the carburetor to a grid in the manifold during warm up. Marked cold driveability improvements were noted with the EHS. The 1977 levels were achieved by the aluminum intake manifold equipped system. System emissions without the aluminum manifold were not stated by Chrysler. Initial tests on an electric fuel vaporizer have shown 50% CO reductions over the first two minutes of the 1975 FTP. Also the engine ran very smoothly and required much less additional fuel to operate than was anticipated according to Chrysler. A single plane "hot well manifold" has been developed with an improved hot spot for faster warm up. Initial tests indicate a 20% improvement in distribution with this manifold.

An improved EGR system is to be developed to increase the EGR rate at low vacuum and keep the percent diluent more constant. This should be similar to proportional EGR systems that others have had for some time now. Also, an electronic EGR system is being prepared for testing. The super-proportional "Goodwille" EGR system which provides increased EGR rates during acceleration was not mentioned by Chrysler. Other notable systems for which little or no new data were presented were the modulated AIR system, the TCCS V-8, or the prechamber stratified charge 225.

Table Chrysler-6

Electric Hot Spot Evaluation

Vehicle 1- 1974 360 CID Fury, no catalyst, no AIR, two-plane intake

	HC	CO	NOx	Fuel Economy
With EHS	1.28	14.75	1.82	10.07
Without EHS	2.01	15.61	1.80	10.03

Vehicle 2- 360 CID Fury with lean carburetion (.056-.061 F/A), EGR, no AIR, no catalyst, single-plane intake

	HC	CO	NOx	Fuel Economy
With EHS	1.48	14.1	5.2	11.62
Without EHS	1.68	17.7	4.45	11.73

Vehicle 3- 1973 360 CID Fury II with oxidation catalyst, AIR, EGR two-plane intake

	HC	CO	NOx	Fuel Economy
With EHS	.22	1.97	2.10	10.8
Without EHS	.25	2.01	1.80	10.4

Table Chrysler-7

Aluminum Intake Manifold Evaluation

Vehicle - 318 CID, Automatic, 4500 lb. IW, with modified spark advance, venturi vacuum amplified EGR, AIR, and a UOP catalyst.

HC	CO	NOx	Fuel Economy
.24	2.3	1.74	12.8
.33	2.5	1.82	13.3
.31	3.7	1.72	13.5

Table Chrysler-8

1975 FTP Fuel Economy of Chrysler Models

Engine	Trans.	IW	1974** Fuel Economy	1975 Fuel Economy	1975 % Change From 1974	1977 Fuel Economy	1977 % Change From 1974	1978 Fuel Economy	1978 % Change From 1974
225	A3	3500	16.9	17.1	1	--	--	--	--
225	M3	3500	--	--	--	18.1***	--	--	--
225	M3	4000	12.0	14.5	21	$14.5^1/15.2^1$	24	--	--
318	A3	4500	--	10.7/13.0	--	12.1^2	--	--	--
360-2	M3	4500	10.0	12.9	29	--	--	--	--
360-2	A3	5000	10.9	11.4	5	--	--	$9.6^3/11.4^4$	-12/5
360-4	A3	5000	10.0	--	--	$10.9^1/11.0^1$	10	--	--
400-4	A3	5000	8.7	10.9	25	10.6***/ 11.9***	29	--	--

1 1977 1st choice system w/o start cat.
2 base metal NOx catalyst + 10° retard
3 Questor system
4 Dual catalyst - No EGR

** corrected from 1974 to 1975 FTP
*** 1977 1st choice system

7.1.2.2 Durability Testing Programs

Durability Testing Programs - 1977 Model Year

For the .41 HC, 3.4 CO, 2.0 NOx level, Chrysler has assembled a five car fleet of 'C' body (full size) cars for durability testing. The cars are equipped with 400 CID engines and several variations of their "miniconverter" system which places the catalysts immediately behind the exhaust manifolds. The variations in this fleet include different catalyst sizes and loadings along with different exhaust heat valve arrangements. No mileage or emissions data were reported.

Durability Testing Programs - 1978 Model Year

At levels below 2.0 NOx Chrysler reported limited progress on their evaluation of NOx catalysts. This effort involves three cars equipped with the following NOx catalysts: noble metal on ceramic substrate; an ICI catalyst on ceramic substrate; and a base metal on metallic substrate. The best durability was achieved with the noble metal catalyst which had a total of 20,000 miles when the test was terminated due to engine problems. The deterioration of this catalyst was very slight over this mileage. The ICI equipped car produced the lowest emissions at the start but was significantly degraded after 10,000 miles. Chrysler has halted all durability testing pending further developmental progress on systems at this emission level.

7.1.2.3 Progress and Problem Areas

Progress and Problems - 1976 Model Year

Chrysler has made and is making progress toward reducing the cost and improving the fuel economy of their 1976 models. The changes are extensive enough, however, to require Chrysler to recertify most models for 1976. Chrysler has also gained valuable field experience with a 100-car fleet of catalyst-equipped vehicles. This field experience has been valuable to Chrysler by identifying user problems such as warm-up driveability, detonation, and odor. Because this test started in January, 1974, Chrysler stated that they were able to remedy many problem areas in their 1975 models.

Progress and Problems - 1977 Model Year

At the 0.41 HC, 3.4 CO, 2.0 NOx level, Chrysler has made much progress in the development and evaluation of the subsystems that might be used for a full-effort system. Testing of improved catalysts, miniconverters, improved warm-up devices, improved EGR, improved exhaust manifolds and improved air injection systems has all been carried out on a developmental basis. The major problem for Chrysler at the 0.41 HC, 3.4 CO, 2.0 NOx level is that the combination and optimization of the total 1977 package does not yet seem to have been accomplished. This is not too surprising, since the report team has observed that many manufacturers develop the components of advanced systems separately and only put them all together when it is very clear that they are going to have to meet the standards that such full-effort systems require. Chrysler apparently is not at this point yet.

An additional problem for Chrysler at the 0.41 HC, 3.4 CO, 2.0 NOx level is the lack of durability testing of the entire 1977 package. Some tests may be just beginning, however the systems may not include all of the 1977 components, and the fleet apparently consists of only 7 vehicles.

Progress and Problems - 1978 Model Year

Chrysler has made some progress in the areas of catalyst screening and evaluation. NOx catalysts made by Chrysler and other catalyst manufacturers have been bench tested. A limited amount of vehicle low mileage testing was reported by Chrysler but no extensive durability results were reported. Chrysler has tested a Gould GEM-68 catalyst system with oxygen getter, but the vehicle was not equipped with EGR. Chrysler stated in their status report that the vehicle was going to be durability tested in the future. The report team learned that the system was destroyed by the combination of fuel run out and ignition failure on several tests before the vehicle was to be durability tested. See section 7.2.1.

Chrysler's problems at the 0.4 NOx level remain lack of system development and durability testing of full-effort systems.

7.1.3 Ford

7.1.3.1 Systems to be Used - 1976 Model Year

The 1976 Ford systems are described in table Ford-1. Both Engelhard and Matthey-Bishop catalysts are used. Noble metal loadings are of 66 percent platinum and 34 percent palladium for Engelhard catalysts and 93 percent platinum and 7 percent other noble metal for Matthey-Bishop catalysts. Ford uses three different monolithic substrates in nine different sizes including either oval or circular cross sections. The "half pass" (only half of V-8 exhaust is catalytically treated) catalyst system will be used on all engines larger than the 302 CID except on the 351 CID Granadas and Monarchs. Catalyst protection is achieved by venting the air pump to the atmosphere when the vehicle floor temperature exceeds a predetermined value. Improved EGR systems are discussed in the Ford application for certification; however, they are not used in 1976. These include the RELIC or recirculating exhaust gas load induced control system for EGR reduction during prolonged cruise conditions and an exhaust backpressure modulated EGR system. Both are more proportional than current EGR systems and according to Ford can provide up to 1 mpg improvement in fuel economy at the 2.0 NOx level. Spark delay valves, heated intake air, and electric assit chokes are some minor systems frequently used by Ford.

Changes in costs and economy for the 1976 models were not stated by Ford. In the opinion of the report team there is not much chance of improved fuel economy over the 1975 models unless the California AIR, EGR, oxidation catalyst (full pass) systems are recalibrated to the 1.5 HC, 15.0 CO, 3.1 NOx level.

Systems to be Used - 1977 Model Year

The Ford emission control systems to achieve the .41 HC, 3.4 CO, 2.0 NOx are not finalized; however, the current first choice system is AIR, EGR, and oxidation catalyst. Larger, improved monolithic catalysts will be used with the exhaust backpressure modulated EGR, high energy ignition (HEI), and variable venturi (2700 series) carburetors on some models. Remaining models will use conventional carburetors. Internal engine changes will include reduced valve overlap for improved low speed operation and combustion chamber modifications to improve fuel economy and emissions. The Ford introduction of HEI lags behind others in the industry, but should provide some improvements in emissions, driveability, and fuel economy.

Ford estimated that the initial retail cost of the 1977 vehicle will average $150-$200 more than the 1975 vehicle due to increased cost of the emission control systems. Also, Ford indicated that an unknown fuel penalty would be realized in 1977. This could not be verified by the report team due to the absence of fuel economy data in the Ford status report. Ford later stated that "vehicle testing to date (of backpressure EGR system) indicates a potential increase of up to .5 to 1.0 mpg".

Table Ford-1

1976 Ford Emission Control Systems

Engine CID	AIR Drive Ratio	EGR	Oxidation Catalyst Loading (tray oz)	Oxidation Catalyst Manufacturer
140 (2.3 "A")	(.95)	Ported		
140 (2.3)	(.95)	Ported	.06	E
171 (2.8)	(.95)	Ported	.02	M-B
200 A	(1.37)	VVA	.11	E
250	(1.37)	VVA	-	
250 (1CEF)	(1.37)	VVA	.11	E
302 "A"	(1.46)	VVA	.04	M-B
302 (1CMF)	(1.46)	VVA	-	
302 (2CMF)	(1.50)	Ported	.04	M-B
351W "A"	(1.46)	Ported	-	
351W (1CEF)	(1.46)	Ported	.11	E
351W (1CET)	(1.46)	Ported	.05	E
351M/400 (1CET)	(1.46)	Ported	.05	E
460	(1.25)	Ported	.07	E

VVA = venturi vacuum amplified
E = Engelhard
M-B = Matthey-Bishop
"A" = Alternate engine

The 1977 emission levels have been achieved at low mileage with vehicles using the 140, 171, 250, 302, 400, and 460 CID engine. Vehicles powered by the 140 and 400 CID engine have demonstrated the 1977 levels at 50,000 miles. Seven Ford vehicles achieved the 1977 levels in 1975 certification. Included were vehicles powered by the 140 and 250 CID engines and the 360 and 390 truck engines.

Systems to be Used - 1978 Model Year

The first choice Ford system for the .41 HC, 3.4 CO, 0.4 NOx level will include a 3-way catalyst followed by a "clean up" oxidation catalyst with secondary AIR between the two catalysts, the exhaust backpressure modulated EGR system, and electronic fuel injection or sonic carburetion with feedback control. Also some cylinder head and inlet manifold modifications will be made. The sonic carburetor will probably be a Ford model rather than the Dresserator as Ford has shown considerable interest in duplicating Dresser's results with Ford hardware.

A 2.3 litre Pinto using Bosch L-Jetronic fuel injection with oxygen sensor feedback, EGR, secondary AIR, a 3-way catalyst, and a clean-up oxidation catalyst has achieved .14 HC, .70 CO, and 1.5 NOx at low mileage over the 1975 FTP. Average driveability was rated at 5.0 as compared to the minimum 5.5 rating of acceptability Ford would prefer. Also a 2.8 litre Capri has achieved .23 HC, 2.08 CO, and .30 NOx at low mileage over the 1975 FTP while using two 3-way catalysts (one in each bank), dual oxygen sensors, and EFI. Average driveability was rated acceptable at 6.8.

The Gould NOx catalyst in a dual catalyst system is an alternate system. Gould achieved .24 HC, 3.3 CO, .26 NOx, and 12.5 mpg with their system on a 351W Galaxie at low mileage without the oxygen "Getter". Ford could not duplicate these levels after receiving the vehicle. Further testing is planned using the GEM 68 catalyst with the "Getter".

The Questor system is another alternate system. An early Questor system achieved the 1978 levels on a 351 5000 lb. inertia weight vehicle at low mileage and then deteriorated rapidly. Similar results occurred with an improved Questor system on a 2.3 litre Pinto. The Pinto will receive system modifications and further testing.

Other Systems

Systems using start catalysts and exhaust HC storage canisters have been studied and dropped. The start catalyst, despite much improved warm up characteristics, were said to have poor durability. HC storage canisters were said to have safety and purging problems.

Single cylinder tests will be conducted to optimize the "fast burn" concept. Increased EGR tolerance is expected to provide lower NOx emissions, lower octane requirements, and improved engine efficiency with a HC emissions penalty due to lower exhaust temperatures. Modulated AIR experiments are being conducted to optimize air flow rate.

Three different sonic carburetors are being studied. Two are Ford models and the third is the Dresserator. A Dresserator equipped Galaxie without catalysts, EGR, or AIR was tested by the California Air Resources Board in May of 1973. The vehicle achieved .32 HC, 4.7 CO, 1.58 NOx, and 10.8 mpg on the 1972 FTP. On a 1975 FTP basis these results would be .28 HC, 3.4 CO, and 1.6 NOx. Spark retard was utilized to lower HC emissions below the .41 level. CO and NOx emissions were unaffected by retard. The fuel economy was 7 percent better than the average 1973 vehicle of the same weight class. Driveability of this vehicle was judged to be acceptable by EPA personnel. Data from Dresser indicated that without spark retard, fuel economy can be improved by 20 percent while HC emissions double. With a catalytic control system, the Dresser vehicles could have fuel economy better than uncontrolled cars and achieve the .41 HC, 3.4 CO, 2.0 NOx levels. The Ford development program has demonstrated the hot start results in table Ford-2 without AIR, EGR, or catalysts.

Table Ford-2

Hot Start Sonic Carburetor Results

	HC	CO	NOx	MPG
Ford Hinged Jaw	.42	4.99	1.45	9.9
Dresser Model II	.74	5.47	1.38	11.2

Ford indicated that sonic carburetors could not be in significant production until 1979. The report team believes that serious development could provide a cost effective sonic carburetor-catalyst system for 1977.

Ford is also studying both the prechamber and direct injection PROCO stratified charge engines. An agreement was signed with Honda to jointly develop CVCC engines for Ford. The Pinto and Torino emissions are not typical CVCC results on the 1975 FTP, as can be seen from the Galaxie results in table Ford-3.

Table Ford-3

Ford CVCC Results on the 1975 FTP

	HC	CO	NOx	MPG
Pinto 140 M 3000	2.86	14.96	1.70	20.8
Torino 400 5000	.68	4.77	2.04	9.6
Galaxie 400 A 5000	.21	2.51	1.81	9.9
	.19	2.32	1.87	10.1
	.29	2.77	1.80	9.9
	.24	2.20	1.58	10.6
	.18	2.26	1.88	9.2
	.24	5.14	1.66	10.5
	.22	2.72	1.69	9.4
	.24	2.32	1.60	10.5
	.15	2.17	1.83	9.1
	.15	1.67	2.36	9.3
Average Galaxie Results	.21	2.60	1.81	9.9

CVCC System

No efforts were reported to recalibrate the Ford CVCC vehicles to the 0.4 NOx level which has been consistently achieved by Honda 119 CID models. Ford claims the prechamber CVCC "program has been delayed as result of uncertain future NOx standards. A viable production program requires that these prechamber engines can be mass produced if NOx emission standard is retained at the 2.0 gm/mi level for at least ten years..." In the opinion of the report team, the program has been delayed because of Ford's reluctance to demonstrate that the .4 NOx level can be achieved while requesting an emissions standard moratorium. Furthermore, the report team is doubtful that Ford CVCC introduction would occur at the 2.0 NOx level. Conventional engines can obtain the 2.0 NOx level at as good or better fuel economy than that demonstrated by the 400 CID Ford CVCC's. The report team does not wish to criticize the CVCC approach as we feel that with EGR optimization and exhaust aftertreatment, the CVCC approach may prove to be competitive at the more stringent 1978 levels in both emissions and fuel economy. Ford indicated that some EGR studies will be made in the future.

A dynamically scavenaged prechamber system which eliminated the additional inlet valve has been dropped because of poor fuel economy. No supporting data was provided. An "add-on" prechamber device is also being studied. No data was provided for this system either.

American Bosch, Robert Bosch, and Nippon-Denso are preparing fuel injection systems and cost estimates of their proposed systems for mass production of the PROCO. Champion Spark Plug is doing similar work with spark plugs for the PROCO. The 351 PROCO equipped Montego continued durability testing in 1974 at NOx levels recalibrated to about 2.0-3.0 NOx. The higher NOx calibrations failed to provide significant changes in fuel economy. HC and CO emissions tended to increase as the NOx levels were reduced, however. Similar conventional Ford vehicles achieved about 11 mpg in 1975 certification. The 400 CID Ford engine was also converted to PROCO in 1974. The first effort was the "Super Economy" Mark IV. All systems were optimized for fuel economy and 14.1 mpg was achieved over the 1975 FTP; however, driveability and combustion harshness were unsatisfactory. Three other 400 CID PROCO vehicles were tested for NOx levels of 1.5-2.0. Early results were reported as in table Ford-5. Fuel economy of comparable 1975 conventional Ford models was about 10 mpg.

Table Ford-4

351 CID PROCO Results Without Catalysts

HC	CO	NOx	MPG
5.54	22.0	.383	14.3
1.32	18.2	1.01	14.0
1.82	25.9	1.48	13.5
1.38	15.6	1.90	14.6
1.15	15.6	3.22	14.2

Table Ford-5

400 CID PROCO Results Without Catalysts

	HC	CO	NOx	MPG
Montego 90° Inj. Spray Angle	1.41	18.0	1.16	12.6
Montego 60° Inj. Spray Angle	1.51	12.7	1.71	13.1
Torino 100° Inj. Spray Angle	2.10	8.06	1.50	14.4

7.1.3.2 Durability Testing Programs

Durability Testing Programs - Update of 450 Car California Fleet

This fleet consists of 450 Ford sedans equipped with 400 CID engines. The cars are basic 1973 production with the addition of monolithic oxidation catalysts along with a catalyst overtemperature protection system and the Ford air injection (Thermactor) system for reducing HC and CO. These vehicles have been assigned to three large fleet operators. Ninety of the vehicles are serving as a control group and are being emission tested periodically. The remaining 360 vehicles and the control groups will be tested whenever there is a customer complaint. Forty-three vehicles in the control group have now completed 24,000 miles. The average emissions level for these 43 vehicles has remained below the .41 HC, 3.4 CO, 2.0 NOx level. Some preliminary conclusions of Ford were that the oxidation catalysts experienced a decreasing rate of deterioration and that CO and NOx emissions were affected by the maintenance performed. Nineteen catalyst failures were experienced. All of the failures involved partial melting of the catalysts and were attributed by Ford to misfiring caused by faulty ignition systems. The catalyst overtemp protection circuit which dumps the Thermactor air supply was ineffective because sufficient air was already in the exhaust to cause catalyst damage.

In addition, a set of four vehicles is being tested to evaluate the performance of catalysts and exhaust systems on rough road and general durability schedules. The two rough road cars have gone their scheduled 8000 miles with no reported problems. The two general durability cars have accumulated 48,000 and 49,450 miles respectively, with no catalyst problems reported.

A Dearborn 20-car fleet is accumulating customer type mileage. Equipped identically as the previously mentioned fleets except for the addition of a breakerless ignition system, these cars are being operated by Ford engineers with close attention being paid to performance, warm-up and driveability characteristics. Seventeen cars are at or beyond 15,000 miles and one car has reached 45,000 miles. The emissions level of the car at 45,000 miles was 0.70 HC, 4.26 CO and 1.60 NOx. Three catalyst failures were experienced as the result of ignition system breakdown.

Durability Testing Programs - 1977 Model Year

At the .41 HC, 3.4 CO, 2.0 NOx level Ford has four durability/evaluation efforts underway. The "1976 Catalyst Durability Fleet" initiated in July 1973, consists of 12 vehicles representing a cross-section of the Ford model line. This fleet was established to evaluate the effectiveness of different catalyst volumes and suppliers in reaching the 50,000 mile durability goal at the .41 HC, 3.4 CO, 2.0 NOx emission level. Nine vehicles have reached the 50,000 mile mark and one vehicle is at 25,000 miles. The remaining two vehicles were eliminated at 35,000 and 45,000 miles, respectively, due to catalyst melting problems. The 12 vehicles consisted of two each of six different models. Four of the six model types averaged above the .41 HC, 3.4 CO, 2.0 NOx level at 50,000 miles.

The "1977 Catalyst Technology Fleet" is a second effort at the .41 HC, 3.4 CO, 2.0 NOx level. Thirty-five vehicles began accumulating mileage in May 1974 with more advanced monolithic catalysts employing larger volumes and cell densities. Mileage to date on the vehicles ranges up to 30,000. The highest mileage emission data reported was for four vehicles at the 25,000 mile level. At this point the vehicles were well below .41 HC, 3.4 CO, 2.0 NOx level. As with the "1976 Catalyst Durability Fleet", this fleet is receiving corrective maintenance based on emission levels, which is not allowable in official EPA procedures. Ford explains this maintenance practice as best fulfilling their goals for engine/catalyst system development.

Ford is also operating a "Pelleted Catalyst Fleet" utilizing the GM pellet catalyst in 16 vehicles. The objective of this fleet is to provide performance and deterioration information that will enable Ford to objectively evalutate monolithic versus pelleted catalysts. An average of 40,000 miles has been accumulated. No failures were reported but the emission data at the higher mileages shows the average levels of all cars to be in excess of .41 HC, 3.4 CO, 2.0 NOx.

The fourth Ford effort at the .41 HC, 3.4 CO, 2.0 NOx level is the "Feed Gas PAS Fleet". The objective of this effort was to attain predetermined feed gas (non-catalyst) emission levels on vehicle fleets tested at sea level and at altitude. The selected levels represented Ford's estimate of the degree of emission control needed up-stream of the catalyst to meet the .41 HC, 3.4 CO, 2.0 NOx level at the tailpipe. The majority of the sea level fleet met the feel gas level goal but the fleet at altitude was unsuccessful. The sea level and altitude fleets consisted of eight and five cars respectively which represented a cross section of Ford models. A total of 4000 miles was accumulated on each car.

The Ford PROCO (Programmed Combustion) engine has undergone additional durability testing. Equipped with oxidation catalysts and EGR the 351 CID PROCO engine was installed in a 1972 Montego. The system was calibrated to meet the .41 HC, 3.4 CO, 2.0 NOx level. Since Ford's 1973 Status Report the car has accumulated 16,000 miles of additional AMA Durability, completing 50,000 miles. Some emission system failures were experienced but the engine and injection system were relatively trouble free. The fuel economy ranged between 13-15 mpg.

Durability Testing Programs - 1978 Model Year

Ford reported progress on two vehicle durability tests of systems targeted for NOx below 2.0 gm/mi. The first test involved a 20,000 mile test of a Questor equipped 351W-2V Ford. The emission level at zero mileage was 0.04 HC, 2.0 CO, 0.39 NOx. The HC and NOx levels remained low through 15,000 miles but the CO control deteriorated steadily, reaching 7.86 at 20,000 miles. The HC control deteriorated rapidly between 15,000 and 20,000 miles where it jumped from 0.41 to 5.07 gm/mi. Ford reported that secondary air system malfunctions and low compression in one cylinder accounted for much of the degradation.

The second Ford effort at NOx below 2.0 was a 2.3L Pinto equipped with Questor's third generation system which includes their own integrated reactor - reverter exhaust manifold. The zero mileage emissions were comparable to the Ford described above, but the system control deteriorated quickly due to an insufficient secondary air system. The test was stopped at 360 miles and the vehicle was returned to Questor for modification.

7.1.3.3 Progress and Problem Areas

Progress and Problems - 1976 Model Year

Ford is apparently going to use model year 1976 as a refinement and optimization period for their emission control systems. They will certify to the same emission standards for 1976 as they did for 1975, therefore the systems could be the same, and they are, for the most part. Ford's approach using the half-pass system will be continued on most large engined-vehicles. Ford could have used 1976 as a year to try and certify full catalytic control systems that might have allowed them to catch up some to their competition in fuel economy, but the report team feels that Ford does not want to accept the extra cost or the possibility that they might certify too low and meet the 1977 standards (one* of their trucks with full catalytic treatment did in 1975).

Progress and Problems - 1977 Model Year

Ford has made significant progress in system selection for 1977. All models will use full catalytic treatment of the exhaust gas, along with improved catalysts, backpressure EGR, and high energy ignition. Ford is depending heavily on the improved catalyst technology being developed for them by their suppliers and now being tested and evaluated by Ford. This improved catalyst technology, which Ford expects to achieve improved conversion efficiency at high mileage, results from improvements in catalyst material and larger catalyst volume.

Ford is also investigating other areas which may have impact on systems for the 0.41 HC, 3.4 CO, 2.0 NOx level. Among these radial flow monoliths, 2_rO_2 - copper chromite base metal oxidation catalysts, and sonic carburetion. It may be that these developmental areas are investigations for future (post-1977) introduction, and Ford claims the sonic carburetor can only be in production in 1979. Part of the length of time necessary for the introduction of a sonic carburetor, in the opinion of the report team, is Ford's evident desire to develop their own sonic carburetor like Dresser's, and they may be repeating some of the work already done by Dresser.

Ford is rather unique in that they are running developmental durability fleets targeted toward 0.41 HC, 3.4 CO, 2.0 NOx. Most manufacturers are not. These fleets are being used to screen and evaluate catalysts for possible use in model year 1977. Ford did not supply detailed descriptions of the vehicles being durability tested, so it is not known if the systems included all of the components that Ford actually plans to use in 1977. Because another fleet will be started after the two fleets are finished the report team concludes that the durability data submitted by Ford was on less than full effort systems. Even though, the results for the vehicles with highest mileage were below the 0.41 HC, 3.4 CO, 2.0 NOx levels at 25,000 miles.

---

* The durability vehicle was above the 1977 level

Progress and Problems - 1978 Model Year

Ford's "current choice" system, a three-way catalyst plus an additional oxidation catalyst is indicative of the status of Ford's efforts to meet the 0.41 HC, 3.4 CO, 0.4 NOx standards. In the judgement of the report team systems like the 3-way + ox. cat. under consideration by Ford are inferior to dual catalyst systems in their potential for achieving the 0.4 NOx standard. The report team has concluded that Ford, like other manufacturers, is developing this type of system in anticipation of a NOx target higher than 0.4, and Ford also does not now plan to have to meet 0.4 NOx.

Indications of Ford's attitude toward meeting 0.4 NOx were evident more than one year ago, as pointed out in last years report, when Ford redirected their alternate engine programs to a 1.5 NOx target. The report team concludes that Ford's conventional engine effort is also targeted toward a NOx level higher than 0.4, and that this decision is also about a year old.

Ford's efforts with independent developers of systems with potential for 0.4 NOx capacity has been minimal in the past year. Ford learned of the Gould GEM 68-getter system in February 1974. Currently, almost one year later, Ford reported no tests on such a vehicle. Ford has tested a Questor system in the past year and typical of most automobile manufacturers' relationships with independent developers, the vehicle was tested, something was found to be wrong with it, and the vehicle was returned to Questor to have them fix it.

Ford continues to work on their PROCO engine program. However, the redirection away from 0.4 NOx has not permitted the evaluation of the improved injection systems for HC reduction in conjunction with a system targeted toward 0.4 NOx. This is considered by the report team to be unfortunate, since the biggest problem with the PROCO at 0.41 HC, 3.4 CO, 0.4 NOx has always been HC, not NOx.

7.1.4 General Motors

7.1.4.1 Systems to be Used - 1976 Model Year

The General Motors systems for 1976 will be nearly identical to those used in 1975 with a few revisions for improved fuel economy. The 1976 Federal system will include quick chokes, EGR, and oxidation catalysts on virtually all models.

Table GM-1

1975 GM Control Systems for 49 States Models

		AIR	EGR	CAT
Chev	140		Ported	160
Chev	262	X	Ported	260
Chev	250		Ported	260
Chev	350-2		Ported	260
Chev	350-4	X	Ported	260
Chev	400-4	X	Ported	260
Chev	454-4	X	Ported	260
Pont	350-2		Ported	260
Pont	400-2		Ported	260
Pont	350-4		Ported	260
Pont	400-4		Ported	260
Pont	455-4		B.P.	260
Olds	260		B.P.	260
Olds	350-4		Ported	260
Olds	455-4		Ported	260
Buic	231		Ported	260
Buic	350-2		Ported	260
Buic	350-4		Ported	260
Buic	455-4		Ported	260
Cadi	500-4		Ported	260

All catalysts are pellet type with either cylindrical or spherical pellets. The 160 CID and 260 CID converter both contain about .05 troy ounces of noble metal. The noble metal is 71% platinum and 29% palladium.

California 1976 models will be very similar to the 49 state models with AIR added.

Systems to be Used - 1977 Model Year

GM has several catalytic control systems under consideration for the .41 HC, 3.4 CO, 2.0 NOx level. One is an extension of the 1975 Federal system to include previously developed systems such as AIR, proportional

EGR, EFE, and intake manifolds with improved distribution. Another catalytic system uses very lean carburetion in conjunction with an oxidation catalyst. EGR and AIR are eliminated. Also studies are to begin to evaluate small manifold-mounted "start" catalysts for use with the larger main catalyst. Previous experience with manifold-mounted catalysts should prove valuable.

The report team feels that the very lean carburetion plus oxidation catalyst system is potentially one of the more initial cost effective systems we have seen demonstrated at the 1977 emissions level. The Chevrolet 400-4 vehicles are shown in Table GM-2 and can be compared with the extended 1975 catalyst approach. The fuel economy of all three prototypes is down from the 13-14 mpg of the comparable 1975 Federal vehicles. Other prototypes at 1977 levels also show fuel economy losses from the 1975 models. Not all systems were complete; however, this does indicate that the 260 CID pellet catalyst may no longer be capable of doing all the work. A catalytic system with improved "light off" characteristics could help eliminate the fuel economy losses. One GM vehicle did achieve the 1977 levels in 1975 certification.

Table GM-2

1977 Systems Comparison

	HC	CO	NOx	Fuel Economy
AIR, EFE, backpressure EGR, ox. cat.	.15	1.4	1.5	10.7
Lean burn, ox. cat.	.17	.8	1.9	10.8
2 data points	.24	1.2	1.8	10.6

Systems to be Used - 1978 Model Year

GM systems for the .41 HC, 3.4 CO, .4 NOx level use catalyst technology. Proportional EGR and EFE are used with all systems. One is a dual catalyst system with reduction catalysts mounted near the exhaust manifolds and the oxidation catalyst in the underfloor location. Slightly rich A/F mixtures provide the reducing atmosphere and secondary AIR provides the oxidizing atmosphere. A 3-way catalyst system is also being considered. An oxygen sensor will provide feedback control to either an electronic fuel injection system or a carburetor for near stoichiometric A/F control. Another system includes the 3-way catalyst followed by secondary AIR and a "clean up" oxidation catalyst.

All three systems have demonstrated the 1976 levels at low mileage, but durability has not been established for any of them. GM effort at .41 HC, 3.4 CO, and .4 NOx in 1974 consisted of testing on one dual catalyst vehicle, two 3-way catalyst vehicles, and one 3-way plus "clean-up" catalyst vehicle. The Nippon-Denso NOx catalyst in the dual catalyst system completed 24,000 miles below .4 NOx.

The 3-way catalyst vehicles at the 1978 levels have shown the potential for fuel economy equivalent to their excellent 1975 GM counterparts as shown in table GM-5. Dual catalyst vehicles exhibited somewhat poorer fuel economy due to their richer carburetion to create the reducing atmosphere in the NOx catalyst.

Other Systems

Alternate engine development has received considerable attention at GM. The prechamber stratified charge engine appears to be the most likely to succeed, but all indications are that it would not appear during the time frame of this report. GM is concerned that exhaust aftertreatment devices will be needed at 1978 levels to reduce fuel economy losses. Honda converted both the GM 140 and 350 CID engines to stratified charge some time before GM did; however, no joint Honda-GM development program was reported.

Table GM-3

Prechamber Stratified Charge Results

CID	IW	Control System	HC	CO	NOx	MPG
350*	5000	—	.15	2.72	1.66	10.5
350	5000	—	.9	4.5	1.7	10.3
350	5000	Thermal Reactor	.26	3.0	1.5	9.8
350	5000	Catalyst	.19	.9	1.5	10.2
350	4000	—	1.2	4.1	1.4	12.5
350	4000	EGR	2.8	8.1	.43	11.7

*Honda CVCC conversion, done by Honda.

A GM stratified charge Vega was assembled in early 1974, but no test results were reported to EPA.

A dual shaft, regenerated gas turbine has been reported which has achieved .12 HC, 2.14 CO, and .36 NOx over the 1975 FTP. This vehicle was not fully described, but at least part of the engine control system used was not contained in the vehicle. Practical in-vehicle installation of those components has not been achieved. Fuel economy of this vehicle was not stated; however, fuel economy and cost were said to be specific problems. Single shaft turbines are also being investigated. In the opinion of the report team, gas turbines will not be competitive in the automotive market until a materials breakthrough permits significantly higher temperature turbine operation.

The Diesel powered Opel 2100D was mentioned as having 20% better fuel economy than a similar gasoline version over a low speed cycle, but according to GM it will not be imported due to small demand and problems with the Diesel engine. These engine problems include combustion noise, particulate emissions, exhaust odor, and cold starting, according to GM. GM also noted the inability of the Diesel to certify at the 1978 NOx level.

The rotary engine program has slowed considerably since GM postponed its introduction. According to GM, "Our decision was based primarily on the conclusion that we did not possess emission technology which would permit us to meet the 1977 standards at reasonable fuel economy levels". The report team concluded that when optimized for fuel economy, GM's rotary is barely competitive with conventional engines. Since emission controls beyond those which are fuel penalty-free are needed to make GM's rotary meet even the 1975 Interim standards, the engine is not competitive in fuel economy. Table GM-4 compares the GM rotary fuel economy to that of other 1975 vehicles of similar inertia weight and power to weight ratios. It should be noted that the GM rotary-engined vehicle in table GM-4 does not meet the 1975 Interim standards, while the other vehicles do.

Table GM-4

GM Rotary Fuel Economy Comparison

	Fuel Economy	
	City	Highway
GM Rotary 206	14.5	20.5
Buick 231 V-6	20.3	25.3
Volvo 164	16.5	26.5
Mustang II V-6	15.5	22.7

No further information was presented on the GM super EFE system which forces all the vehicle exhaust through the intake manifold to aid in cold start fuel evaporation. Also no new data was presented on the cold start HC storage system.

7.1.4.2 Durability Testing Programs

Durability Testing - 1975/1976 Model Year

General Motors has acquired extensive field durability experience at the 1975/1976 Federal and California emission levels through their "COPO" fleet. This fleet consists of 205 Chevrolets and is split into two emission design levels: 146 cars at the 1.5 HC, 15 CO, 3.1 NOx Federal level and 59 cars at the .9 HC, 9 CO, 2.0 NOx California level. Each level is further divided into underfloor catalyst and manifold catalyst vehicles. The manifold catalysts are mounted immediately behind the exhaust manifolds.

Table GM-5

Current Fuel Economy of Various Systems

Mfr.	Engine	Trans.	IW	1974	1975 Federal	% Change from 1974	1975 Calif.	% Change from 1974	1977	% Change from 1974	1978	% Change from 1974
Chev.	140-1	A3	3000	19.5	19.0	-3	--	--	--	--	20.4^{5}	+5
Chev.	350-2	A3	5000	11.0	12.4	+13	--	--	--	--	12.2^{2} 12.1^{3} 10.3^{3} 9.6^{4}	+11 +10 -6 -13
Chev.	400-4	A3	4500	--	13.8	--	--	--	10.7^{6} 10.8^{1} 10.6^{1}	--	--	--
Olds	350-4	A3	4500	9.7	14.6	+51	12.6	30	11.0^{7}	+13	--	--

[1] lean burn and ox. cat.
[2] 3-way cat.
[3] 3-way cat. + ox. cat.
[4] dual cat.
[5] 3-way cat. + EFI
[6] extended 1976 Calif. ox. cat.
[7] Above without AIR

GM reports that over 8,000,000 miles have been logged by the COPO fleet. The type of service is primarily taxicab and the reported results were generally good. The average emission levels of reported sample groups were within the design goals and system durability appeared to be good. The California 2.0 NOx level came closest to being exceeded with the average level at 50,000 miles being approximately 1.9 gm/mi. A total of 20 catalyst failures were experienced, but seven of these occurred after 50,000 miles and four involved monoliths. All catalyst failures resulted from overtemperature conditions caused by engine misfiring. The misfiring was attributed to overly lean carburetion and fouled spark plugs.

GM reported that occasional inadvertant fueling with low lead fuel, 0.5 gm/gallon, did not result in measurable catalyst deterioration. GM also reported the results of an investigation of catalyst fouling on lead and phosphorous. After 3,000 miles of operation on leaded fuel, an underfloor catalyst car and a manifold catalyst car were operated for 7,000 miles on unleaded fuel. The underfloor catalyst regained nearly all of the lost efficiency but the manifold catalyst did not recover. Following 6,000 miles of operation on high phosphorous fuel, the catalyst efficiency of several cars was cut in half. Subsequent operation on clean fuel did not result in catalyst recovery. GM reported that the catalyst durability of the AMA schedule car was fairly typical of the taxi and highway groups.

Durability Testing - 1977 Model Year

A second filed durability test is being conducted by GM on 25 Oldsmobiles operated in California under customers service conditions. Thirteen of the cars were tailored to meet the .41 HC, 3.4 CO, 3.1 NOx level and the remaining twelve were targeted for the .41 HC, 3.4 CO, 2.0 NOx level. All of the cars were equipped with EGR, EFE and HEI and, in addition the 2.0 NOx cars have air injection.

The thirteen cars in the first group have accumulated between 25,000 and 33,000 miles and the second group has accumulated between 17,000 and 21,000 miles. Both groups average emissions are below the design goals but several vehicles have exceeded the goals on individual tests. The average emissions for eleven cars of the first group at 24,000 miles were .24 HC, 2.54 CO, 1.90 NOx and the average for five cars of the second group at 16,000 miles was .37 HC, 1.44 CO, 1.46 NOx. It should be noted that maintenance was performed on the emission systems prior to testing, a procedure not allowed in official EPA certification testing.

The fuel economy results of the Oldsmobile fleets are interesting because the second group of cars with lower emissions had better fuel economy. The average dynamometer fuel economies were 9.03 MPG for group 1 and 10.05 for group 2. GM reported that the evaporative control systems strongly influenced the cold start emissions. The average emissions were reduced from .21 HC, 3.16 CO, 1.93 NOx to .17 HC, 1.93 CO, 1.86 NOx by substituting an empty canister for the normal canister prior to cold start.

GM reported low mileage emissions data on 41 proving ground cars which GM stated represented the "current state-of-development" toward meeting the .41 HC, 3.4 CO, 2.0 NOx requirement level. The data indicates that hydrocarbon control is the area needing the most improvement. It is difficult to assess the probability of these cars complying with the requirement at high mileage because practically no data was given for above 2000 miles.

Durability Testing Programs - 1978 Model Year

At the .41 HC, 3.4 CO, 0.4 NOx level, GM reported AMA durability data on 14 dual catalyst systems. However 13 of these had completed testing in 1972 and 1973. Only one additional dual catalyst system was tested on the AMA schedule in 1974. The car tested in 1974 exceeded the HC and CO allowable level at 8000 miles and exceeded the NOx level at 25,000 miles. GM reported additional dual catalyst durability testing involving 18 cars in the COPO fleet. The emissions performance of this group was very unsatisfactory. The average NOx level exceeded 0.4 at zero miles. At 8000 miles the average emissions of HC, CO and NOx all exceeded the 1978 standard levels. GM reported durability test data for two cars equipped with three-way catalysts. These cars operated on the AMA schedule. Both cars experienced rapid catalyst deterioration.

7.1.4.3 Progress and Problem Areas

Progress and Problems - 1976 Model Year

GM plans to use basically the same systems for 1976 as they did in 1975, therefore the report team concludes that GM will have no major problems in model year 1976.

Progress and Problems - 1977 Model Year

GM has made progress in the area of system development and optimization for model year 1977. GM's major problem in meeting the 1977 standards is HC control. Tests run by GM with '77 prototype vehicles equipped with 50,000 mile catalysts from 1975 certification showed that HC emissions were generally too high. The GM approaches toward improving the HC control capability lie in two areas, improving the 1975 systems and the lean burn plus ox. cat. approach.

The improved 1975-type systems are much like the GM 1975 California systems that had PEGR and air injection. GM is evaluating improved catalysts to go with this system, along with the use of a start catalyst. The warm-up converter was discussed very vaguely by GM and no data on such systems was supplied. This is a good example of an advanced control approach possibly being held in the wings until it is needed. Ford stated that one of the problems they saw with their GM pelleted catalyst fleet was the deterioration of light-off capability, which a start catalyst would help. GM has developed other approaches like fuel distillers, charcoal traps, and super EFE that were investigated and then not used because they did not have to be, and possibly because they tended to be more costly.

GM's second approach for 1977 could have few if any of these extra-cost hurdles to overcome, in the opinion of the report team. The lean burn plus ox-cat approach does not use EFE, EGR or an air pump, therefore this system can have significant cost reduction potential, in the opinion of the report team. This system also may have HC problems since GM's lean burn technology does not appear to have the HC control capability that the best lean burn systems have (Dresser's, for example). The GM lean burn approach, coupled with improved catalysts and/or start catalysts has the potential to meet the 0.41 HC, 3.4 CO, 2.0 NOx levels at lower cost than current systems, in the opinion of the report team.

Not much in the way of durability testing of advanced 1977 systems was reported by GM, another problem area. Based on GM's status report, the report team concludes that GM is waiting to see what happens in the suspension hearing before they gear up to test such improved systems extensively, although it appears that the lean burn plus ox-cat approach will be continued anyway because of its cost potential.

The most far-reaching problem at the 0.41 HC, 3.4 CO, 2.0 NOx level for GM has been the inability to develop a control system that gives the HC control needed for the rotary engine. Despite using systems that may be considered too complicated or expensive for the conventional engine, GM could not get the HC as low as necessary with a catalyst system, and they did not want to use the thermal reactor approach. The report team concludes that GM won't be able to certify their catalyst-equipped rotary at 0.41 HC although thermal reactor technology as demonstrated by Toyo Kogyo can do it. For GM to be able to use the catalyst approach they will have to improve the basic engine as Toyo Kogyo is doing, possibly by going stratified charge. If the standards are 0.9 HC, GM may have a slight chance with their rotary, although with approximately a 10 HC engine-out level, it is going to take some doing, (a catalyst efficiency on HC of over 90 percent at 50,000 miles is implied).

Progress and Problems - 1978 Model Year

GM has had a low level of effort at the 0.41 HC, 3.4 CO, 0.4 NOx level for about a year now, evidenced by the fact that they ran only one NOx catalyst car last year. GM, like other manufacturers appears to be developing 3-way (or 3-way plus ox-cat) systems in preference to dual catalyst systems, with a higher NOx target than 0.4 NOx. The major problem with the 3-way catalysts is conversion efficiency at extended mileage.

The most promising low NOx results reported by GM were those from the GM CVCC-type engine with EGR, 2.8 HC, 8.1 CO, 0.43 NOx, with no oxidation or reduction catalyst. GM did not report any results with this system with an oxidation catalyst. If the efficiencies of the GM tests with a catalyst, but without EGR, are used report team estimates that the GM CVCC-type engine with an oxidation catalyst and EGR would have low mileage levels of 0.59 HC, 1.62 CO, 0.43 NOx, quite an accomplishment for a 4,000 lb. vehicle with no catalytic control of NOx.

GM also appears to have made progress in another area related to emissions, but not specifically mentioned by GM as emission control technology. This is in the area of vehicle weight. Past GM development vehicles targeted toward 1977 and 1978 standards have ranged over the current GM inertia weight range, with most of the test vehicles being in the 5,000 and 5,500 lb. inertia weight classes. However, this year's status report showed most of the larger vehicles being tested at 4,000 and 4,500 lb. inertia weight, indicating to the report team that GM's full size cars may be significantly lighter in the 1977-1978 time frame. This lighter weight is in the direction of improving both emission control capability and fuel economy. The report team hopes that the inference of lighter weight full-size GM cars in the future that we drew from their status report is correct.

7.2 Independent Developers

The automotive industry has historically relied on a vast number of suppliers for all kinds of components from fasteners to frames, vee-belts to valve springs and wheels to windshields. While most manufacturers build their own engines, many of the components used in and on the engines are purchased from suppliers. These engine related components can include; pistons, piston rings, bearings, bolts, valves, spark plugs, carburetors, etc. When emission control devices became necessary the industry often looked to their suppliers not only for the actual production of the hardware but the design expertise as well. The best example of an emission control device that has been designed and developed outside the industry is the catalytic converter. Some domestic manufacturers have developed considerable capability in this area but the suppliers generally have more capability in the catalyst area than the automakers themselves.

Much of the emission control hardware developed by suppliers has been reported on by the automakers in their annual status reports but several suppliers have done a sufficient amount of work independent of any auto manufacturer to warrant separate coverage in this section of the report. The four most significant non-auto manufacturer developers in the past year have been:

1. Gould, Inc.
2. Dresser Industries
3. Yamaha
4. Questor Automotive Products.

The position the suppliers take on the feasibility of meeting the statutory emission standards for 1977 and 1978 is somewhat different than the position taken by most automobile manufacturers, especially the domestic manufacturers. The suppliers have a vested interest in the maintenance of the standards as they hope to sell the technology and hardware necessary to achieve compliance. The automakers, on the other hand, cannot "sell" the low emission characteristics of their cars to the average new car buyer. To an automaker the standards represent a cost that has little benefit, in our opinion. The emission control development approach taken by the suppliers has generally been more aggressive than that taken by the automakers.

7.2.1 Gould

Gould, Inc., a multi-divisional organization with headquarters in Chicago, has been involved in the development of metallic NOx catalysts for several years. Gould's interest in catalyst development was precipitated by materials requests made of

Gould's "Clevite" bearing division by Ford and Chrysler. The auto industry was familiar with Gould as an OEM supplier of components. Other Gould products include; copper foil (for circuit boards), dry cell batteries, small electric motors, torpedoes, powdered metal products, rubber suspension components, air filters and oil filters.

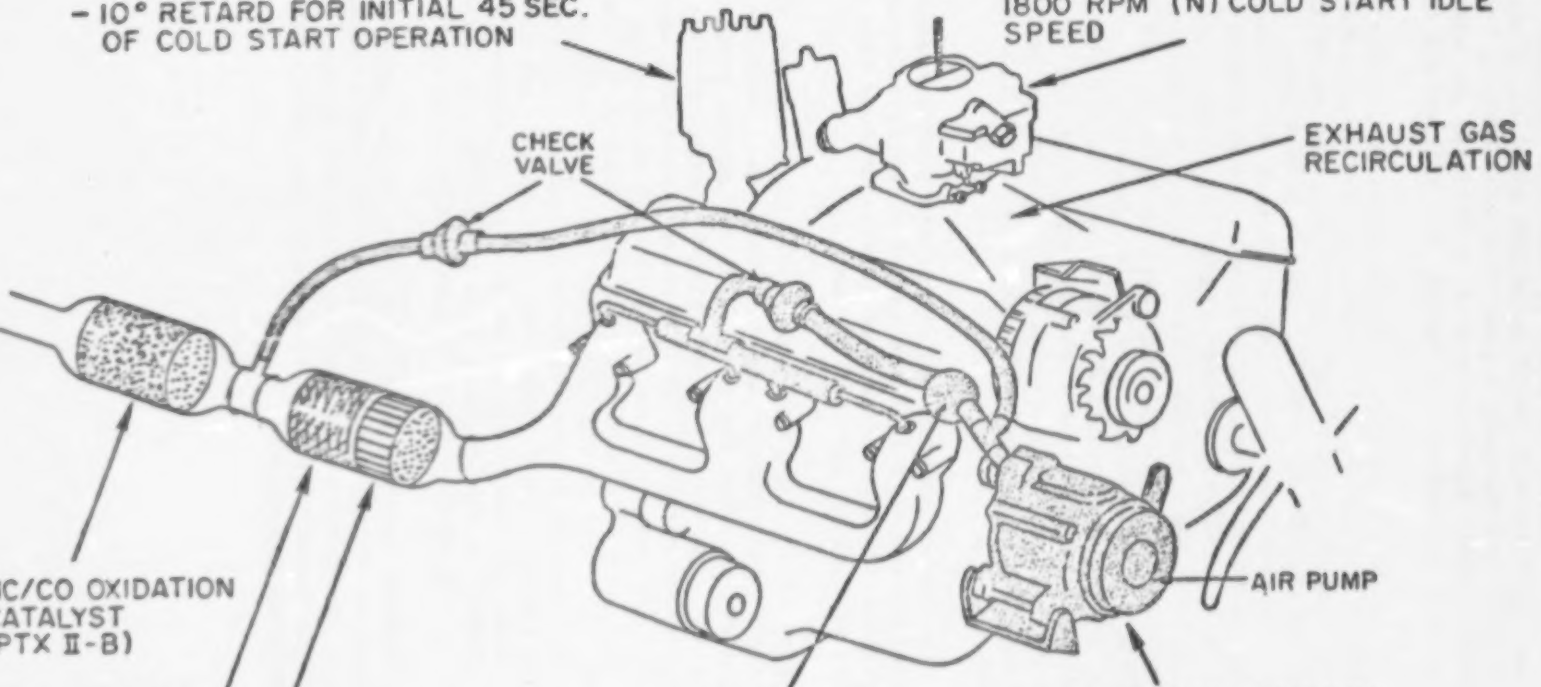
The metallic reduction catalysts developed by Gould were discussed at great length during the 1976 Suspension Hearings. The Gould catalysts are designated as "GEM" (Gould Emission Material) followed by a number (e.g., GEM 45, GEM 67, GEM 68) to designate specific versions of the catalyst. Gould's catalyst, a monel based metallic catalyst deposited on a metallic wire mesh, demonstrated very high efficiency on several test vehicles (most built by Gould) but the durability aspects were questionable. Several automobile manufacturers reported catastrophic catalyst failures at low mileage. Even the best data, accumulated by Gould, showed rapidly decreasing efficiency beginning at around 20,000 miles. It was the report team's judgement at that time ('76 Hearings) that the lack of sophisticated fuel metering systems and air metering systems on the prototype vehicles was responsible for much of the poor durability performance.

Gould has also theorized that the durability problems were due to poor metering and they felt the amount of catalyst deterioration was proportional to the frequency of lean excursions (too much air entering the engine per unit of fuel).

Since the time of the 1976 Hearings, Gould has continued to invest in NOx catalyst development. Recent efforts have been devoted to finding a way to solve the poor metering induced problems without actually improving fuel metering. Instead of relying on outside sources to develop a fuel metering system that would keep oxygen spikes (as occur on lean excursions) from reaching the NOx catalyst, Gould has developed a triple bed catalyst system to solve the problem. In front of the usual two beds (NOx catalyst and oxidation catalyst) is a small oxidation catalyst that functions as an oxygen remover. With this system installed lean excursions no longer affect the NOx catalyst because the O_2 remover, or "Getter", eliminates the oxygen before it reaches the NOx catalyst. A schematic of the Gould Getter system is shown in Figure 7.2.1.1.

During the federal emission test, 4 percent oxygen spikes which normally occur on shifts and decelerations are almost completely eliminated by the first bed of the new three bed system. This performance was demonstrated to a member of the report team in Gould's Cleveland laboratory.

GOULD GETTER SYSTEM



- DISTRIBUTOR
  - 1970 HI-PERFORMANCE
  - 10° RETARD FOR INITIAL 45 SEC. OF COLD START OPERATION

- CARBURETOR
  - SLIGHTLY RICH (~1.5% CO)
  - 90-120 SEC. ELECTRIC CHOKE WITH 1800 RPM (N) COLD START IDLE SPEED

CHECK VALVE

EXHAUST GAS RECIRCULATION

AIR PUMP

- HC/CO OXIDATION CATALYST (PTX II-B)

- NO_x REDUCTION CATALYST (GEM 68)

- OXYGEN REMOVAL CATALYST (1/2 PTX II-B)

12V SOLENOID FOR PORT AIR CONTROL

- AIR INJECTION SCHEME
  - COLD START
    120 SECOND PORT INJECTION
    2-3% RESIDUAL O_2 AT CATALYST
  - HOT START
    45 SECOND PORT INJECTION
  - CONTINUOUS SECONDARY INJECTION TO OXIDATION CATALYST

Getter System Durability

Extended durability testing of the new Getter system has been run on four vehicles and one engine dynamometer setup. The engine dyno test did not really test the capability of the getter to protect the GEM catalyst from oxygen spikes as transient operation was not included. The test did show, however, that when the latest Gould catalyst, GEM 68, is not subjected to oxygen spikes it can retain high, stable efficiency for 50,000 miles worth of exhaust gas. Table 7.2.1.1 contains a summary of the dyno test.

Table 7.2.1.1
Steady State Conversion Efficiency
"50,000 Mile" Engine Dyno Test
GEM 68 with O_2 Getter

"Mileage"	Percent NOx Conversion (NET)
0	79.0
20,000	72.6
30,000	79.8
40,000	78.8
50,000	77.7

At the conclusion of the test Gould reported the substrate of the catalyst had lost some ductility but no crumbling was evident. Whether or not physical integrity would have been maintained had the catalyst been subject to the vibration and shocks occurring in an "over the road" test was not, however, determined by this particular test. Gould also reported the microstructure of the catalyst indicated some surface generation but not to the extent leading to an exfoliation failure.

One vehicle test had reached 50,000 miles. The results are shown in Table 7.2.1.2.

Table 7.2.1.2
50,000 Vehicle Durability
Datsun 610 with GEM 68, getter, PTX OXCAT

Mileage	HC	CO	NOx
0 (1 test)	.43	3.5	.47
5,000 (4 tests)	.52	3.7	.44
15,000 (4 tests)	.51	2.6	.37
25,000 (9 tests)	.72	2.1	.40
35,000 (3 tests)	.70	4.6	.41
42,000 (2 tests)	.93	6.5	.70
50,000 (2 tests)	.79	4.5	.95

NOx values remained low until the testing at 42,000 miles. Inspection of the catalyst revealed the rear support plate for the catalyst had broken and allowed the rolled coil of metal mesh to telescope rearward. The catalyst was pushed back together and a new backplate was installed but activity remained low. Gould theorized that the poor efficiency resulted from a non-uniform exhaust gas flow distribution through the catalyst bed as the result of high localized exhaust gas velocities eroding the catalyst surface when it was in the "telescoped" condition after the backplate failure. The backplate failure that caused this condition is readily solvable, in the opinion of the report team.

Three larger vehicles have reached 25,000 miles of durability and their high mileage results are shown in Table 7.2.1.3.

Table 7.2.1.3
25,000 Durability Results
Gould Getter System Test Cars

Vehicle	HC	CO	NOx	75 FTP MPG	1975 Counterpart
4500 In. 351 CID with EGR (3 test avg.)	.47	2.5	.33	12.3	11
4500 In. Chevrolet 350 CID with EGR (4 test avg.)	.42	3.4	.38	13.7	13
4500 In. Chevrolet 350 CID with EGR (2 test avg.)	.76	4.7	.27	12.9	13

These are impressive results in light of the fact that no advanced HC control techniques were employed and EGR systems were simple non-proportional units. Fuel economy was essentially equal to the 1975 versions of the same cars despite the sub - .4 NOx performance. NOx conversion efficiency of the GEM catalysts has been relatively stable on all three cars since low mileage testing.

Other Testing Programs

Gould is involved in a program with the state of New York involving the in-service testing of three Staten Island Police cars equipped with their system. These vehicles are still at low mileage and will be periodically tested by the N.Y. City lab as they accumulate mileage.

Gould has dealt with many automobile manufacturers including; GM, Ford, Chrysler, AMC, Mercedes, Toyota, Toyo Kogyo and Nissan. At the writing of this report the level of effort on Gould's system by each of these manufacturers is low, and has been low since EPA's public announcement that 0.4 NOx might be unnecessary.

Gould's in-house durability programs have always shown substantially better performance than any programs involving an automobile manufacturer. Testing at the automakers has often resulted in catastrophic catalyst failures due to total ignition failures and some unexplained events. In the summer of 1974, for example, Gould delivered a vehicle to Chrysler for testing which had met the 1976 levels at Gould's laboratory in Cleveland. Table 7.2.1.4 is a listing of the events which occurred with the vehicle (car #178):

1. Car delivered to Chrysler by Gould.

2. Chrysler experiences misfire en route to proving ground for emission testing.

3. Chrysler mechanic experiences total ignition failure at speed while looking for problems with car.

4. Catalysts returned to Gould for checking. X-Ray analysis and steady state efficiency tests are okay.

5. Chrysler re-installs catalyst on test car, runs out of gas on emission test due to fuel weight system foul up.

6. Chrysler takes car to proving ground. Experiences two ignition failures and runs out of gas in first 12 hours of testing.

7. Car is sent back to Chrysler engineering, runs out of gas again on emission test.

8. Damaged catalysts are returned to Gould.

Gould has consistently demonstrated superior capability at optimizing for low emissions with vehicles using their NOx catalyst despite the fact that their experience with automotive systems optimization is minimal compared to that of the auto industry.

EPA has been involved in confirmatory emission tests and particulate emission tests of Gould vehicles over the past year. Preliminary particulate test results indicate there is some nickel emissions from high mileage catalysts but the type of nickel compound emitted and the emission rate has not been firmly determined and more work is underway. There is some evidence that the Gould vehicles have a large (40-50%) fraction of methane in their HC emissions. This might be expected from the steam reforming that could occur across the NOx catalyst bed. If further tests validate preliminary data, it would mean that the total HC emissions from Gould vehicles are less harmful than from 'oxidation catalysts only' vehicles. If this is the case a non-methane HC standard would be particularly beneficial for vehicles using the Gould system.

Progress and Problem Areas

In the last 12 months, Gould, Inc. has made more progress toward the demonstration of 0.4 NOx than all domestic car manufacturers combined, in the opinion of the report team. Besides demonstrating superior NOx catalyst efficiency Gould has shown the potential for achieving low NOx levels and good fuel economy simultaneously.

Gould's major problem is lack of industry support in the system optimization area where Gould lacks expertise. Advanced control hardware such as proportional EGR, EFE, etc. has not generally been used during manufacturers tests of Gould's catalyst and such hardware has not been made available to Gould for their own testing.

Particulate emissions from the NOx catalyst are a potential problem that needs further quantification.

Indications are that if sub-1.0 NOx levels are not required, at least in California, by the 1978 and 1979 model year, Gould will go out of the catalyst business.

7.2.2 Dresser

Dresser Industries, like Gould, is a multi-divisional company which produces a variety of products including, gas station pumps, tools, safety valves, and oil drilling equipment. Since 1970 Dresser has been involved in the development of a sonic carburetor known as the "Dresserator". Dresser felt the potential for the carburetion system, which was formerly under development at Stanford Research Institute, was sufficient to allow them to eventually obtain licensing fees from the automobile industry for its use.

The Dresser concept is to achieve fine fuel atomization over a wide range of operating conditions by maintaining a choked flow condition in the carburetor throat and metering fuel upstream of the throat so that is must pass through the shock wave that occurs when the flow goes sub-sonic in the diffuser which is located downstream of the throat. The extremely fine droplet sizes reportedly created by the Dresserator (10 micron diameter) allow uniform air/fuel ratios (A/F) to be achieved during warm-up and transient conditions that cause A/F variability problems with coventional carburetors. The wall wetting that occurs with conventional carburetors is less of a problem for the Dresserator. With the quality of mixture supplied by the Dresserator the theoretical benefits of lean (18-19:1 A/F) operation can be achieved in practice.

The achievement of sonic flow in a carburetor is not a new accomplishment. Conventional carburetors experience sonic conditions at idle and extremely light load operation where the ratio of manifold to ambient pressure is less than .528. The Dresser carburetor, however, maintains sonic conditions over most of the engines operating range including modes where intake manifold pressure approaches ambient pressure. This is accomplished by the variable area, converging-diverging geometry of the Dresserator. Figure 7.2.2.1 is a schematic of the Dresserator geometry. Movement of a slider between two fixed jaws accomplishes the throat area changes necessary as the engines air requirement changes. Previous versions of the Dresserator have employed moveable jaws without a slider and annular geometry with a vertically moveable cone to vary throat area. Figure 7.2.2.2 is a prototype Dresserator completely assembled.

Emission Performance

Dresser equipped vehicles tested by EPA and others have demonstrated that the level of "untreated" emissions necessary to achieve the 1977 Federal Standards (.41, 3.4, 2.0) with a catalytic aftertreatment system can be achieved with excellent fuel economy. In order to achieve the 1977 levels the pre-catalyst emission levels need to be:

$HC = .41 \div (1-.6) = 1.03$
$CO = 3.4 \div (1-.7) = 11.33$
$NOx = 2.0 \div (1-0) = 2.0$

Levels lower than these have been demonstrated by Dresser on several vehicles. The report team knows of no instances where Dresser has been unable to achieve these levels when high volume exhaust manifolds are used to promote the thermal oxidation of HC and CO in the exhaust. Even without catalysts Dresser test vehicles have approached or equaled the 1977 standards when some spark retard is used to reduce HC. The use of catalysts will, in the opinion of the report team, allow Dresser equipped vehicles to simultaneously achieve fuel economy that is superior to the economy achieved by typical vehicles in any previous model years, including uncontrolled. Typical non-catalyst emission levels for Dresser equipped vehicles are shown in Table 7.2.2.1.

Auto Manufacturer's Cooperation

Cooperative studies have been carried out with Ford, GM, and Chrysler with Ford showing the most interest. Ford and Holley Carburetor have signed licensing agreements so far. No manufacturer is showing a level of effort that is indicative of a commitment to mass produce the system.

Progress and Problem Areas

Dresser's progress in the last year has been in the area of design refinement. Major emphasis has been placed on making the Dresserator mass producable. No significant progress in the emissions or fuel economy area appears to have been made in the last year but none was really necessary to stay well ahead of the capability of other induction systems. No significant efforts appear to have been made to adapt the Dresser to non-lean burn approaches such as 3-way or dual catalyst systems but Dresser, like most auto manufacturers, sees little need for low NOx systems in light of EPA's position on the need for stringent NOx control.

A problem has been that the demonstration of a Dresserator in combination with other advanced emission control systems has not been pursued by any manufacturer. A "Dresser with catalyst" demonstration would take all of one week to accomplish but has not yet been reported.

Dresser's main problem appears to be the result of the radically different design of their Dresserator. The report team saw no evidence that the Dresserator is not at least as mass producible as the conventional carburetor but the significant changes in production facilities that are probably necessary to build the Dresserator must be a square pill for the industry to swallow. If the industry accepts the production facility renovation necessary to build Dresserators, the report team estimates the 1977 statutory standards can be achieved with better fuel economy than has ever previously been achieved in production and at lower system costs than for 1975 cars.

Table 7.2.1

Dresser Test Results
No Catalysts

Vehicle	Inertia Weight	'75 FTP Emissions HC	'75 FTP Emissions CO	'75 FTP Emissions NOx	FTP MPG	Typical Uncontrolled Car of Same Weight, MPG
Ford 351 CID w/Dresser carb and large exhaust manifold.	4500	.41	4.7	1.30	11.3	12.2
Chevrolet 350 CID w/Dresser carb and std. manifolds	4500	.88	4.7	1.70	12.9	12.2
Chevrolet 350 CID w/Dresser carb and std. manifolds	4000	1.18	6.0	1.16	13.4	13.2
Capri 2600 cc w/Dresser carb and large exhaust manifolds	3000	.37	3.9	1.29	17.0	16.1
Levels needed to certify at .41, 3.4, 2.0 with catalysts		1.03	11.3	1.5		

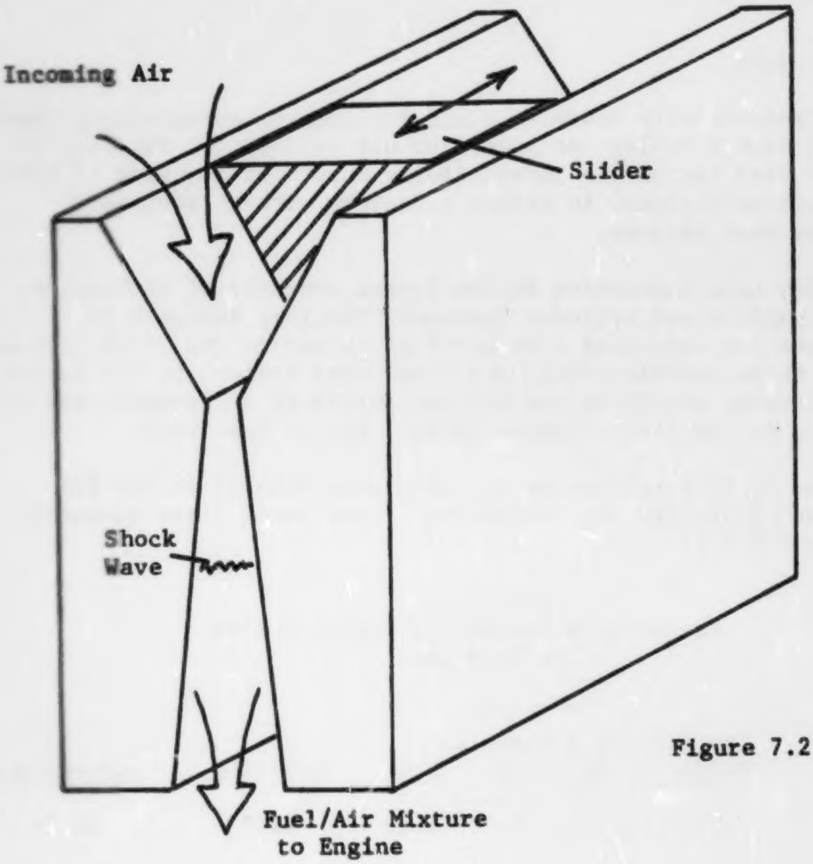

Incoming Air
Slider
Shock
Wave
Fuel/Air Mixture
to Engine

Figure 7.2.2.1

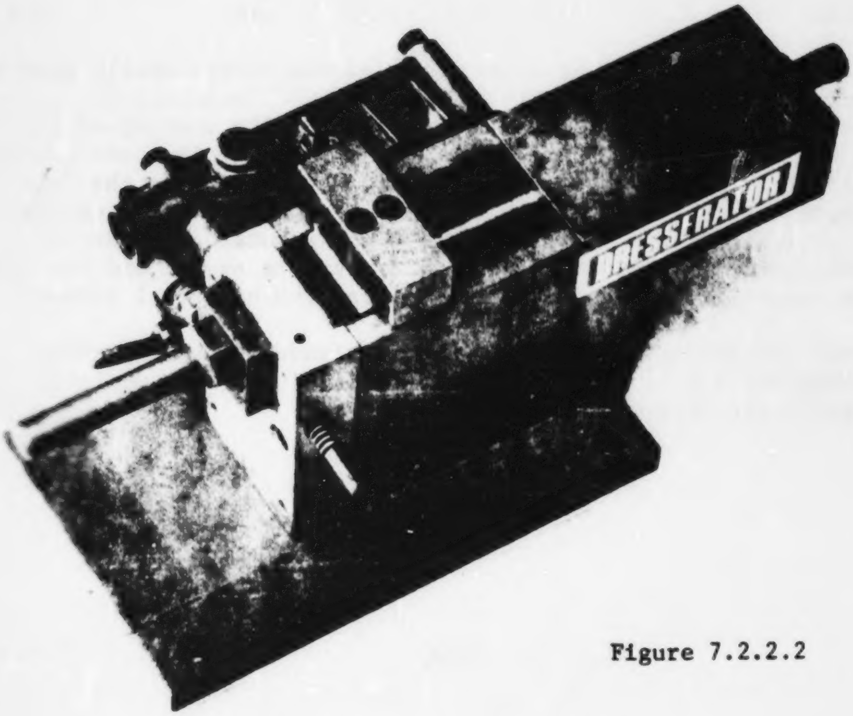

DRESSERATOR

Figure 7.2.2.2

7.2.3 Yamaha

Predominantly known as a manufacturer of motorcycles, Yamaha has also been a builder of passenger car engines for Toyota. In the past year Yamaha has independently developed a system of subtle modifications designed to reduce emissions without adversely affecting fuel economy.

The Yamaha Lean Combustion Engine System consists of carburetor, intake manifold and cylinder head modifications designed to facilitate low emissions with air/fuel ratios in the 17-18:1 range. None of these modifications were considered radical by the report team. Exhaust manifolds are air gap insulated to promote oxidation reactions in the post-cylinder phase. EGR is also used.

In August of 1974 two Yamaha vehicles were shipped to the EPA Ann Arbor Laboratory for evaluation. Test results are summarized in Table 7.2.3.1.

Table 7.2.3.1
Yamaha Lean Combustion Engine System
No Catalysts

		75 FTP grams/mile				
Vehicle	Inertia Weight	HC	CO	NOx	City MPG	Highway MPG
Corolla	2250	.36	3.80	1.18	16.0	28.7
Celica	2500	.34	2.95	2.95	14.5	23.6
Celica	4000	.46	6.87	2.32	14.7	19.4

Emission performance of these vehicles was exceptionally good but fuel economy was lower than the stock (1974) versions of the two cars. The stock 1974 Corolla had city economy of 19.7 mpg in California configuration and 23.6 mpg in the 49-state configuration. Much of the poor fuel economy performance was due to the fact that Yamaha attempted to achieve the 1977 standards without catalytic aftertreatment and had to resort to spark retard to control emissions. At that stage of development the system did not have the capability to meet the 1977 levels with high fuel economy.

Since the EPA testing, Yamaha has continued to develop their system and the latest data, shown in table 7.2.3.2; indicate significant progress is being made.

Table 7.2.3.2
Yamaha Lean Combustion Engine System
No Catalysts

		75 FTP grams/mile				
Vehicle	**Weight**	**HC**	**CO**	**NOx**	**City MPG**	**Highway MPG**
Corolla	2250	.28	2.87	1.87	22.3	34.1

Even without catalysts the Yamaha system demonstrated the 1977 levels can be achieved with good fuel economy using modifications that represent relatively minor changes to currently produced hardware. The report team estimates this system can be mass produced by 1977.

The Yamaha system is catalyst compatible and further fuel economy optimization should be possible if a portion of the emission control burden is shifted to a catalyst. The non-catalyst emission performance of the system is so low that little or no noble metal would be required to stay well below the 1977 standards even with much larger cars.

While the report team does not consider the Yamaha developments to be as significant as the Dresser system, the Yamaha system is a low risk, low cost, approach with few lead time problems that appears capable of achieving the 1977 standards on small cars without catalysts and on larger cars with minimal catalytic treatment. The Yamaha accomplishments are especially significant in light of Yamaha's automotive background, and the short period of time they have been investigating the system.

7.2.4 Questor

Questor is another multi-divisional company with experience in supplying componentry (exhaust systems) to the auto industry. The emission control system being developed by Questor Inc., called the "Reverter" System, is basically a rich thermal reactor, followed by a metallic NOx catalyst, followed by another thermal reactor. No oxidation catalyst is used, and the system is lead tolerant. A schematic of the system appears in Figure 7.2.4.1.

Two years ago, the Reverter system was evaluated by the report team as having at least as much, if not more, potential to attaining the .41 HC, 3.4 CO, 0.4 NOx level as any system that the automobile manufacturers were developing, but that the manufacturers were apparently not interested in the system since it was not compatible with their 1975 oxidation catalyst systems.

Two years ago Questor was actively working on improvements to the Reverter system. One of the drawbacks to some of the early generation Questor systems was their relatively poor fuel economy, which resulted from the rich operation required to keep the reactors and the catalyst hot enough to work efficiently. Typical idle CO values for these early prototypes were 7 to 9 percent, with a resulting fuel economy penalty of up to 20 percent compared to current vehicles. Questor has worked to improve the fuel economy of the system by using a third generation packaging configuration that reduces the heat loss, and by running leaner. In order to keep the NOx levels down, Questor worked with metal suppliers to develop improved NOx catalysts that are more active. Questor estimated that with the latest systems the .41 HC, 3.4 CO, 0.4 NOx levels could be met with no fuel economy penalty over 1974 vehicles.

The most promising results to date have been achieved on the 1800 cc Datsun vehicle shown in Table 7.2.4.1.

Table 7.2.4.1
Questor Reverter System
2750 IW Datsun Vehicle

Configuration	HC	CO	NOx	City MPG
Stock 1973 Vehicle	1.05	8.96	1.80	18.6
Questor System w/Inconel 601 NOx catalyst	.13	2.6	.37	17.6
Questor System w/601 and RA330 catalyst	.15	2.5	.31	17.9
Questor System w/IN 1013 catalyst	.13	2.6	.21	20.1
1978 Standards	.41	3.4	.40	

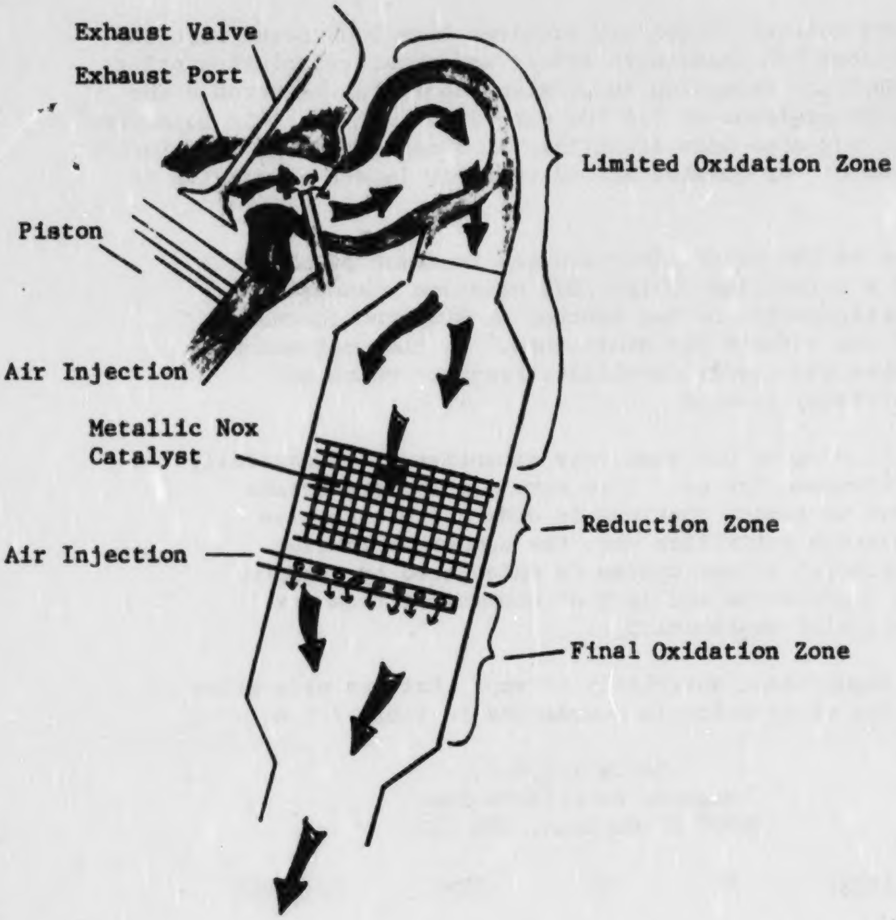

Exhaust Valve
Exhaust Port
Limited Oxidation Zone
Piston
Air Injection
Metallic Nox Catalyst
Reduction Zone
Air Injection
Final Oxidation Zone

Figure 7.2.4.1
Questor Reverter System

Temperature related durability problems have been noted with the Questor system but inadequate effort was spent on solution prior to a significant reduction in program scope that occurred after EPA's public position on 0.4 NOx was aired in 1973. Air injection management has also been identified as a major problem that is not being pursued. As Questor stated in their latest submission to EPA:

> "Due to the uncertainty and the imminent possibility of a relaxation of the 1978 emission standards, particularly for the control of NOx, the intensity of our efforts has diminished. We have not undertaken the costly durability programs which we initially planned.
>
> This program has been very expensive and financially burdensome for us. I am sure you can appreciate that we cannot continue to underwrite extensive research activities when the commercialization potential of our system is endangered by changes in legislation and lack of commitment from our potential customers."

The most significant durability attempt that was made prior to the lowering of priority is summarized in Table 7.2.4.2.

Table 7.2.4.2
Questor Durability Test
5000 IW Pontiac, 400 CID

System Mileage	HC	CO	NOx	Comments
0	.09	3.03	.37	
9,000	.36	2.76	.30	
18,000	.40	2.66	.38	
23,000	.24	1.56	.62	Oxidation of NOx catalyst noted, new catalysts installed.
23,000	.17	2.70	.46	First test with new catalysts, not yet broken in.
28,000	.08	2.89	.61	
36,000	.16	3.05	.41	
47,000	.22	3.5	.32	
50,000	.29	2.99	.28	
51,000	.19	3.22	.27	

Cooperative Programs

Questor has been involved in cooperative testing programs with each of the four domestic manufacturers. Some programs are still continuing but on at a low level of effort.

A 3500 IW Pinto vehicle has recently been built for Ford and low mileage tests showed .14 HC, 2.7 CO, .26 NOx with 15.4 mpg.

A vehicle has been recently built for Chrysler that achieved low mileage results shown in Table 7.2.4.3.

Table 7.2.4.3
Questor Dodge 360 CID

	HC	CO	NOx	MPG
4500 inertia	.39	3.14	.34	10.1
4500 inertia	.20	2.18	.38	11.0
5000 inertia	.31	2.84	.32	9.4
5000 inertia	.15	1.94	.33	9.7

Houston Chemical, a division of PPG, is testing another 3500 IW Pinto vehicle with a Questor system. Low mileage results have been below the 1978 standards.

Progress and Problems

Questor has made significant progress since the demonstration of the first generation systems several years ago. Fuel economy has been significantly improved without affecting the emission performance of the system.

Questor's major problem is that the support needed to further optimize the system is unavailable to them. Often cooperative programs with auto manufacturers are stalled when Questor is unable to prove to a manufacturer that their system can meet the 1978 levels on durability. Cars are often returned to Questor for relatively simple problems which any competent manufacturer should be able to quickly solve by himself. No manufacturer has stepped in and developed the improved fuel metering and air modulation systems needed to further optimize the emissions and economy of the Questor system. The report team estimates the Questor system is mass producible and certifiable at the 1978 statutory levels by model year 1978. Some fuel economy loss relative to 1975 would, however, be anticipated since the improved control approaches needed to further optimize the system may not be available by 1978 even if aggressive development toward such a goal is begun now. Further studies of unregulated emissions from the Questor system need to be carried out if it ever becomes a contender in the future.

7.3 Foreign Manufacturers

7.3.1 Alfa Romeo (Alfa)

7.3.1.1 Systems to be used

Systems to be Used - 1976 Model Year

Alfa is working on the development of emission control systems for two different engine types. The first type is the current DOHC in-line four-cylinder engine currently used in Alfas sold in the US. The second type is a horizontally opposed four-cylinder engine of the type used in the Alfasud vehicle, not now imported into the U.S. These two engines are abbreviated "in-line" and "flat", respectively, in this report.

For model year 1976 Alfa plans to use basically the same control technology for the in-line engine as is used for model year 1975. For the Federal interim standards of 1.5 HC, 15.0 CO, 3.1 NOx the system consists of Alfa's mechanical fuel injection plus inlet air temperature control and air injection. For the California requirements of 0.9 HC, 9.0 CO, 2.0 NOx an oxidation catalyst is added. The converter housing is a flat pancake type, and the catalyst used is a pelleted one supplied by SNAM Progetti. The active material is platinum, and the loading is approximately .07 troy ounces per vehicle. Additional modifications include a new exhaust manifold and slightly different valve timing. Alfa has also experimented with insulated exhaust manifolds but does not now plan to use them for model year 1976. The catalyst by-pass system previously under development has been dropped and a converter overtemperature warning light is now used instead.

The work on the flat engine, originally scheduled for 1977, has been expanded to include a 1300 cc carbureted version. This package might be used for model year 1976, in the opinion of the report team. For the 1.5 HC, 15.0 CO, 3.1 NOx requirements apparently engine modifications and air injection will be used. For the California requirements a monolithic oxidation catalyst supplied by Degussa, with Pt and Ru as active materials will be added. The loading has not been finalized.

Systems to be Used - 1977 Model Year

To meet the 0.41 HC, 3.4 CO, 2.0 NOx requirements Alfa plans to use an improved version of the 1975 California package for the in-line engine. The basic modifications include changes to the inlet system and catalyst changes to obtain higher oxidation efficiency at high mileage. The inlet system changes involve dropping the current 4 throttle (one for each cylinder) setup and replacing it with a single throttle. The basic reason for this, according to Alfa, is that it permits the injected fuel to be vaporized better since the pressure that the fuel sees should be lower for a longer time with the single throttle setup. Alfa thinks that engine out HC may be reduced by 30 to 40 percent with this approach. The drawback to this approach is that the distribution of the valve-overlap induced internal EGR (favored by Alfa) becomes poorer. Alfa is contemplating less valve overlap or adoption of the variable valve timing originally scheduled for model year 1978. The catalyst changes planned for 1977 are the use of a larger volume catalyst (2.0 vs. 1.4 litres) and possibly some increase in noble metal loading.

The control system for flat engine for 1977 has not been determined yet. The first choice system is engine modifications, Bosch L-Jetronic fuel injection with feedback control and an 3-way catalyst. Backup systems are the system with air injection and carburetors instead of fuel injection (no feedback) and the system with the fuel injection but no feedback, and air injection. All systems may use an improved oxidation catalyst now under testing. Although called an oxidation catalyst by Alfa the low mileage results from the L-Jetronic/feedback system indicate that the catalyst is performing as a 3-way catalyst, at least at low mileage with NOx results below 0.4 being common.

Systems to be Used - 1978 Model Year

For the 0.41 HC, 3.4 CO, 0.4 NOx levels, Alfa is investigating four approaches for the in-line engine: a) increased internal EGR obtained by use of variable valve timing, b) some combination of external and internal EGR, c) a dual catalyst system, and d) a 3-way catalyst system.

Alfa is one of the few manufacturers to have considered variable valve timing seriously. This concept is not a new one. Many such approaches have been proposed in the past, but Alfa seems to be far along in the development of such a device. In most engines, the valve timing is chosen as a compromise between low speed - low load operation and high speed - high load operation. Valve overlaps that give good high speed power, for example, generally result in poor idle quality, misfiring and poor driveability at low speeds and loads. The idea of having the valve overlap vary in such a manner to provide the overlap (and hence good idle quality and driveability) at low speeds and loads and increase as speed and load increases is an attractive one from both the specific power output of the engine and NOx emissions. Most NOx is made under loaded conditions, where the increased overlap should provide for more NOx control. Alfa submitted no CVS data on vehicles equipped with variable valve timing, but tests with the conventional system with increased overlap gave NOx emission levels below 1 gram per mile. (0.54 to 0.60 with 50° of overlap).

For 1978 for the flat engine, Alfa plans to use a 3-way catalyst system as its first choice. Backup systems are similar to the 1977 backup systems but with the addition of EGR. The catalyst is a 90/10 Pt/Ru Degussa OM 722/14M on a Corning substrate in a Gillet can. The total loading has not yet been decided. The EGR system is of the external type, something which Alfa has avoided in the past since they feel that internal EGR (via valve overlap) is preferable. The system is in the early stages of development. Alfa also mentioned the possibility of using timed air injection i.e., air injection only on the exhaust stroke of each cylinder. No data was reported on this potentially promising system. Low mileage results with the 3-way catalyst system on the flat engine have been below the 1978 levels at Bosch but not at Alfa, leading Alfa to feel that the results are not attractive enough to begin durability testing.

The following table shows the fuel economy results on the 1975 FTP reported by Alfa for various systems targeted toward various emission standards. In the table N.R. means not reported by Alfa and N.A. means not applicable.

Table AL-1

Systems and Fuel Economy

Engine Type	Emission Standard Target	System	Inertia Weight	Fuel Economy
In-Line	1.5 HC, 15.0 CO, 3.1 NOx	Air Injection (AI)	3000	19.4
Flat	1.5 HC, 15.0 CO, 3.1 NOx			N.A.
In-Line	0.9 HC, 9.0 CO, 2.0 NOx	AI + OX CAT	3000	18.7
Flat	0.9 HC, 9.0 CO, 2.0 NOx	AI + OX CAT	2250	22
In-Line	.41 HC, 3.4 CO, 2.0 NOx	AI + OX CAT	3000	N.R.
Flat	.41 HC, 3.4 CO, 2.0 NOx	3-Way	2250	23.3
Flat	.41 HC, 3.4 CO, 2.0 NOx	F.I. + AI	2250	21
Flat	.41 HC, 3.4 CO, 2.0 NOx	F.I. + AI + OX CAT	2250	18.8
In-Line	.41 HC, 3.4 CO, 0.4 NOx	N.R.	3000	N.R.
Flat	.41 HC, 3.4 CO, 0.4 NOx	3-Way	2250	23

The main observation one can draw from Table AL-1 is that the fuel economy depends on the system used. The most complete data are for the flat engine, which show no trend with decreasing emissions but a trend with different systems at the same emission level (see the 0.41 HC, 3.4 CO, 2.0 NOx case). The flat engined vehicle apparently has the capability to get between 21 to 23 mpg if the correct emission control system is used for the level considered. For the purposes of comparison, Alfa reported that the European version of the Alfasud with emissions much higher than the levels considered in Table AL-1 (3.05 HC, 38.84 CO, 2.23 NOx) delivers 20.4 mpg.

7.3.1.2 Durability Testing Programs

Durability Testing Programs - 1976 Model Year

Alfa is just finishing the 50,000 mile durability testing for 1975 model year certification. Alfa indicated that they are just starting 1975 certification for the 1975 California standards. Therefore, as stated in last year's report, Alfa is behind most manufacturers in their development/certification cycle.

Alfa reported development durability results on three vehicles. Two tests were stopped because the vehicles wore out (they had too many miles on them) and the third test was with a now obsolete catalyst. The most successful test 0.73 HC, 3.9 CO, 1.97 NOx at 47,000 miles indicates that Alfa may have the capability to meet the 1975/76 California requirements. This test was run with Snam catalyst BP-N2. Alfa stated that there was a newer catalyst BP-N3 with better light-off characteristics, but no durability results were reported with this catalyst.

As was mentioned in last year's report Alfa seems to be using certification durability testing as the final development test of their systems for the in-line engine.

Although Alfa apparently plans to market their flat engine in the 1300 cc carbureted, air injection, oxidation catalyst form for 1976 only the report team estimates that much of the development work reported is serving two purposes: Model Year 1976 development and back up for 1977 and 1978 model year systems.

The durability results reported by Alfa seem to be directed toward determing whether 9 inches of catalyst (three, 4 inch diameter by 3 inches long pieces) with no catalyst change or 6 inches of catalyst (2 pieces) with a catalyst change will be certified. Alfa's planned mileage accumulation schedule has been cut back due to a reduction of overtime, elimination of the night shift, and introduction of lower speed limits in Italy. While most of the tests were of a developmental nature, i.e., catalysts not the same as those currently planned, and different engine calibrations were used, the report team estimates that Alfa's changes for meeting the 0.9 HC, 9.0 CO, 2.0 NOx level are good.

Durability Testing Programs - 1977 Model Year

Alfa reported no AMA durability results obtained with systems for the in-line engine specifically targeted for the 0.41 HC, 3.4 CO, 2.0 NOx standards. In the opinion of the report team, Alfa will use the durability results from the official 1975 certification process for California as development information for this level of control.

For the flat engine Alfa did not report any durability results with the first choice (3-way catalyst) system. Alfa feels that it is certain that the oxygen sensors will be available for 1977 production from Bosch, so the only durability results to date have been run with the L-Jetronic fuel injection and oxidation catalyst. The single test reported ran to 14,000 miles with 0.88 HC, 7.01 CO, 1.09 NOx. Alfa stated that some unexpected enrichment occurred during this test, which may account for the high HC and CO levels. In addition it was not reported whether or not the vehicle had air injection or not. If no air injection was used the HC and CO levels would also be expected to be high, in the opinion of the report team.

Durability Testing Programs - 1978 Model Year

Alfa did not report any durability data on systems targeted toward the 0.41 HC, 3.4 CO, 0.4 NOx standards with either the in-line engine or the flat engine.

7.3.1.3 Progress and Problem Areas

Progress and Problems - 1976 Model Year

Alfa has made progress in the last year in the areas of system selection and control technology development. Alfa appears to be in good shape for the 75/76 levels of control, especially if their 1975 California certification durability is successful. Alfa's major problem at these levels is that they are somewhat behind most manufacturers in the development/certification process, but if Alfa does not mind certifying late, this is not a serious problem.

Progress and Efforts - 1977 Model Year

Alfa has progressed since last year enough to have a reasonable idea of what system will be required to meet the 0.41 HC, 3.4 CO, 2.0 NOx standards with the in-line engine. Although the modifications planned to the 1975 California package to meet these standards appear reasonable, durability testing is the final proof, and not much has been done in this area.

Progress has been made in the flat engine development in the area of identifying possible backup systems to the first choice system. Durability testing with flat engine systems targeted toward these levels is less than adequate, in the opinion of the report team.

Progress and Efforts - 1978 Model Year

Not much was reported for the in-line engine at the 0.41 HC, 3.4 CO, 0.4 NOx level. In the opinion of the report team, Alfa's major problem at this level with this engine is the reliance on the variable valve timing system to get the low NOx necessary to certify at this level. Other approaches, for example, dual catalyst or 3-way catalyst were almost just mentioned in passing as being approaches that could be used. This reliance on the variable valve timing and the lack of durability data are the major problems for Alfa with the in-line engine at this level.

Alfa has made more progress with the flat engine at this level. Their 3-way catalyst system has shown some promise at low mileage. However durability testing on this system is far from being adequate.

One problem common to Alfa's entire emission control program is apparently a cut back in the level of effort. Alfa stated that the reduction of overtime and the elimination of the night shift had slowed their progress in the critical durability testing area with all systems.

7.3.2 BMW

7.3.2.1 Systems to be Used

Systems to be Used - 1976 and 1977 Model Year

The BMW system for 1976 and 1977 will be similar to that of 1975. The system includes a rich thermal reactor, AIR, and EGR. Four cylinder engines are carbureted and six cylinder engines have Bosch "L-Jetronic" electronic fuel injection. The EGR system is "two stage" and provides increased EGR during accelerations.

With respect to fuel economy BMW states, "For 1976 and 1977 models a light improvement (up to 10%) can be expected. The omission of the EGR system and spark retard should be possible in the case of a highly sophisticated thermo reactor system". The change in sales-weighted fuel economy from 1974 to 1975 was a minus 14.9% for BMW due to the use of rich thermal reactors. No increase in maintenance cost is expected. The 1977 levels have frequently been met by BMW experimental vehicles and one BMW vehicle* achieved the 1977 levels in 1975 certification. The remaining 1975 certification vehicles were very near the 1977 levels.

The 1977 second choice system includes the addition of oxidation catalysts to the current system should the thermal reactor prove to be undesirable.

Systems to be Used - 1978 Model Year

For 1978 two systems are under consideration by BMW. One is a dual catalyst system, and the other is a 3-way catalyst system with oxygen sensor feedback control to the AIR system.

Other Systems

Improved EGR is planned for 1977 or 1978 introduction. Presumably this will be one of the well known proportional EGR systems. Also a stratified charge engine was briefly mentioned. No data was reported for the stratified charge engine.

7.3.2.2 Durability Testing Programs

BMW reported durability test results for 14 vehicles with emission levels targeted at or below the .41 HC, 3.4 CO, 2.0 NOx level. BMW was generally unsuccessful at meeting these intended levels with the principal problem being high CO emissions. It is noteworthy that a 2002 model was below the .41 HC, 3.4 CO, 2.0 NOx level in the official EPA certification testing for 1975.

---

* The durability car was above the 1977 levels

7.3.2.3 Progress and Problem Areas

Progress and Problems - 1976/1977 Model Year

BMW has made substantial progress with their thermal reactor program. The durability of BMW's thermal reactor is apparently adequate to satisfy BMW. The report team considers BMW's choice of a thermal reactor emission control system to be a reflection of BMW's design philosophy. BMW places much emphasis on the performance and driveability aspects of their vehicles. In the opinion of the report team a thermal reactor design such as used by BMW is probably easier to optimize for performance and driveability, compared to other types of systems that could be used. BMW's system choice is not without drawbacks, however. The design and calibration of BMW's system is such that BMW has suffered a fuel economy penalty for 1975, a year in which many manufacturers achieved gains. Although BMW may have the potential to improve fuel economy somewhat for 1976 via recalibration, the report team considers it unlikely that fuel economy for BMW can be improved greatly over the 1975 values for 1977 due to the system that BMW has chosen to use.

Other problems for BMW at the 1977 levels are marginal CO performance on thermal reactor-equipped vehicles, and continuing misery with the durability performance of development vehicles equipped with catalysts.

Progress and Problems - 1978 Model Year

BMW has made progress in system identification and low mileage development at the 0.41 HC, 3.4 CO, 0.4 NOx levels. The basic systems seem to be 3-way as the first choice and dual catalyst as a backup system. Problems for BMW at this level include catalyst durability with both systems, an apparent lack of testing of the more advanced NOx catalysts with dual catalyst system, and a less than adequate durability program, in the opinion of the report team.

BMW also is developing a prechamber stratified charge engine, but from the reported state of development of this engine, the report team considers it an unlikely candidate for model year 1978 production due to inadequate lead time. Part to this lead time is due to the apparent desire by BMW to develop their "own" engine. While this may be attractive from the patent and/or royalty point of view, the report team considers it likely that BMW may be redoing much development work already done by Honda in the development of the CVCC engine.

7.3.3 British Leyland (BL)

7.3.3.1 Systems to be Used

Systems to be Used - 1976 Model Year

The basic approaches contemplated by BL toward meeting the 1976 standards are very much the same as the approaches used for 1975. Two general types of improvements were mentioned by BL as possibilities for 1976: improved and/or larger catalysts, and fuel injection for some models. Most of BL's effort is going into the improved catalyst area for 1976. They hope to be able to avoid the catalyst change at 25,000 miles which most of their 1975 catalyst-equipped vehicles require. Improvements in HC efficiency at high mileage might allow this to occur, and BL is testing catalysts with improved HC efficiency, although the CO efficiency of the particular catalyst BL is testing (a Johnson-Matthey type 12 C) may have been degraded somewhat.

BL is also developing thermal reactors for many of their engines, and feels that the thermal reactor under development by Jaguar could meet the California requirements of 0.9 HC, 9.0 CO, 2.0 NOx.

In general model year 1976 will see refinements of already existing BL catalyst systems. No information was reported on any changes to the 1975 non-catalyst systems by BL, so the report team assumes that they will remain the same.

Systems to be Used - 1977 Model Year

For the 1977 requirements of 0.41 HC, 3.4 CO, 2.0 Nox, BL is relying heavily on the improved catalyst development now underway for the 1976 model year, although BL feels that the improved catalyst alone will not be enough to allow them to certify to the required levels.

Other developments were reported that might be used at this level. The first, a 3-way catalyst system on a V-12 Jaguar gave 0.5 HC, 4.0 CO, 1.8 NOx at zero miles, the only test reported. BL stated that based on this test they do not consider it feasible to meet the 1977 standards, a statement that the report team considers to be somewhat premature in nature, since it is based on one single test at zero miles.

The second system was a Triumph 4 cylinder engined vehicle with EGR and an oxidation catalyst and, presumably, fuel injection. No air injection was used and the results reported by BL were 0.26 HC, 4.6 CO, 8.0 NOx at zero miles. Obviously, this system needs more development if the NOx figure is correct.

The third system is a thermal reactor development, done by GKN for Rover-Triumph. Low mileage results are, typically, 0.2 HC, 3.3 CO, 1.13 NOx.

Another development reported was the attempt at investigating a quick-heat system for the V-8 Rover, and a parameter test of air injection and catalyst efficiency on the same engine. Improvements in system warm-up were shown, but no improvement in lean limit operation was observed. No CVS tests were reported, with the quick warm-up system. The parameter tests of different air injection configurations and different catalysts were used as a system development tool. The results of the air injection optimization were apparently not tested with a catalyst system on the 1975 FTP, however.

Another development mentioned in passing by BL was an exhaust manifold with integral catalysts. The warm-up performance of such a configuration should be attractive, in the opinion of the report team, if the durability performance is found to be adequate. No data were reported for this system.

Systems to be Used - 1978 Model Year

The basic BL approach for the 0.41 HC, 3.4 CO, 0.4 NOx levels is a dual catalyst system. Use of a 3-way approach is also contemplated, especially since BL stated "most catalyst companies have virtually stopped work on straight reduction catalysts".

Low mileage results have been below the 0.41 HC, 3.4 CO, 0.4 NOx levels with dual catalyst systems.

Tests with a Rover equipped with a Bosch L-Jetronic system and a reduction catalyst used a 3-way catalyst with no feedback gave 0.15 HC, 3.04 CO, 0.22 NOx at low mileage.

Other systems included by BL in the 1978 systems discussion appear to be systems that might be used in the 1978 time frame, not necessarily 0.4 NOx systems.

BL reported continuing tests with the Shell Vapipe system, basically a air/fuel vaporizing and preheating device that uses a heat pipe for heat transfer. Steady state operation was said to be good, but the only CVS test reported was 6.77 HC, 12.71 CO, 4.39 NOx, not especially impressive. The heat pipe system takes a long time to warm up, according to BL.

The stratified charge engine development continues at BL. One design, a modified Diesel engine is of the 3-valve type. Initial results were not so encouraging, which is not surprising to the report team, considering that the basic engine structure was developed for a Diesel, not a gasoline, engine. New configurations are now, or have been, under development by BL in both the 3-valve carbureted version and in a 2-valve, injection version, but no data on any stratified charge engine was reported by BL.

BL's position on fuel economy is that emission-controlled engines have suffered and will suffer great losses in fuel economy to meet standards, quoting data on steady state cruises to show the difference between U.S. and European versions of some vehicles. However, BL also mentioned that on the basis of the LA-4, the 1975 versions of the Jaguars got better fuel economy than the 1974's even though the standards are lower in 1975. This indicates to the report team that the system choice is important for BL as it is for other manufacturers when fuel economy is being discussed. BL feels that the 10 to 20 percent gain shown by the Jaguar models (1975 compared to 1974) will be lost in future years.

7.3.3.2 Durability Testing Programs

Durability Testing Programs - 1976 and 1977 Model Years

BL's durability testing appears to the report team to be a combined catalyst screening/development/durability test program for both the 1976 and 1977 model years. Some durability progress has been made since last year but apparently only a few vehicles have been run with the latest J-M 12C catalyst with improved HC efficiency.

Many of the durability vehicles for which data were reported by BL were exactly the same ones as were reported in BL's status report one year ago with no more miles accumulated.

Some of the more interesting durability data were reported on the Jaguar thermal reactor program. The continued development and testing of thermal reactor systems on Jaguars and other BL vehicles leads the report team to conclude that BL would drop catalysts if they were given emission standards that thermal reactors could meet. Such standards would apparently be 0.9 HC, 9.0 CO, 2.0 NOx.

Durability Testing Programs - 1978 Model Year

At first blush, BL's reported durability testing on model year 1978 vehicles seems impressive, with data reported on 8 systems with over 69,000 total accumulated miles. On closer inspection, however, the report team found that the data reported for 7 of the 8 vehicles was identical to that reported one year ago. In the last year BL has run only one vehicle targeted toward 0.4 NOx a total of 4836 miles. The report team concludes that BL, like most manufacturers, has abandoned development and testing of systems targeted to meet the 0.41 HC, 3.4 CO, 0.4 NOx standards.

7.3.3.3 Progress and Problem Areas

Progress and Problems - 1976/1977 Model Year

BL has made significant progress in the last year, primarily in the evaluation of improved catalysts developed by Johnson-Matthey. BL may be improving to the point where they can go 50,000 miles without a catalyst change in 1976, thereby putting them in a position comparable to the position the domestic manufacturers were in prior to the start of 1975 certification (summer 1974).

Problems for BL with respect to meeting the 1977 standards include less than adequate capability to keep the HC and CO levels below 0.41 and 3.4 at high mileage and the relatively low development and testing reported for systems employing advanced engine modifications (like Rover's EFE system) in conjunction with the latest oxidation catalysts.

Progress and Problems 1978 Model Year

BL's major problems at this level are all related to lack of effort at the 0.41 HC, 3.4 CO, 0.4 NOx levels. Durability testing of 0.4 NOx dual catalyst systems is virtually nonexistent, the latest NOx catalyst systems like Gould's with the getter system were not mentioned, and the level of effort in the 3-way area appears to be very low.

Part of BL's problems may be due to the currently poor financial picture of many manufacturers, including BL, although this was not specifically stated by BL. When things get tight, advanced R & D programs are many times the first to go, and in the opinion of the report team this may be occuring at BL.

7.3.4 Daimler-Benz (Mercedes)

7.3.4.1 Systems to be Used

Systems to be Used - 1976 Model Year

The Daimler-Benz system for 1976 will include AIR, EGR, and oxidation catalysts on their six cylinder, eight cylinder, and four cylinder California gasoline engines. The four cylinder 49-state gasoline engine includes AIR, EGR, and a lean thermal reactor. The eight cylinder also uses Bosch "K Jetronic" mechanical fuel injection. Previous V-8's had used Bosch electronic injection. All oxidation catalysts are mounted in the exhaust manifold. The Engelhard II B catalysts contain .09, .15, and .18 troy ounces of platinum and palladium in a 2:1 ratio in the 4, 6, and 8 cylinder models respectively. EGR sophistication also changes for these respective engines from vacuum controlled EGR to venturi vacuum amplified EGR to two stage vacuum controlled EGR.

The 1976 D-B Diesel model will be identical to those sold in 1975. The only controls are classified as engine modification and include the reverse flow damping valves (RFDV) to eliminate secondary fuel injection for simultaneous HC emissions and fuel economy improvement.

Initial cost increase estimates for the various D-B control systems over the comparable 1975 European models are shown in table DB-1. Maintenance costs are not expected to increase for 1976 except for the cost of catalyst replacement which will be about $400 for the four cylinder including parts and labor. High catalyst cost ($320) is blamed on the small number of catalysts used by Daimler-Benz. Fuel economy of all 1976 gasoline models is expected to be better than in 1975 as shown in table DB-2.

Systems to be Used - 1977 Model Year

D-B systems to meet the 1977 standard of .41 HC, 3.4 CO, and 2.0 NOx will be modifications of the 1976 catalyst systems. The four cylinder gasoline engine will receive a new exhaust manifold and a catalyst of the same size as previously used on the six cylinder. The six cylinder will receive the "K-Jetronic" fuel injection system and transistor ignition. Catalyst loadings are not finalized and catalysts will be supplied by Engelhard and/or Degussa. EGR and AIR systems will be identical to those on 1976 models for all gasoline engines.

Diesel engines will be identical to those of 1976 except that the pneumatic governor of the four cylinder will be replaced by a mechanical governor similar to that of the five cylinder. Also both will get altitude compensation.

Initial cost estimates are again in table DB-1. Maintenance costs are not expected to increase over 1975 except for catalyst replacement costs which will be approximately $460 ($380 parts and $80 labor) for the four cylinder. D-B expects losses in fuel economy only for the four cylinder gasoline models of 12% over the 1975 49 states model. This penalty does not appear likely to the report team as the 1975 California version of the four cylinder* certified well below the 1977 standard (.09 HC, 2.35 CO, 1.42 NOx) at only a 6% fuel economy penalty over the 1975 49 states version. A total of five 1975 D-B certification vehicles from four of five families (2 gasoline* and 2 Diesel) certified below the 1977 level.

Systems to be Used - 1978 Model Year

Two systems are still under consideration by D-B to meet the 0.41 HC, 3.4 CO, 0.4 NOx standard. The first choice is a dual catalyst system with AIR switching, and the second choice is a 3-way catalyst system with an oxygen sensor. Reduction catalysts will replace oxidation catalysts in the exhaust manifolds of the first choice system. The oxidation catalyst will follow and probably be near the engine although other locations are still being considered (near firewall, under floor). The second choice system catalyst would be located similarly to the oxidation catalyst in the dual catalyst system. EGR and possibly AIR may be eliminated with the 3-way approach according to D-B.

Diesel models will not be certified at the 1978 levels as they cannot reach the 0.4 NOx,according to D-B.

Initial cost increase estimates are shown in table DB-1. Maintenance costs again will not increase except for catalyst replacement costs which will be about $750 for the six cylinder model (assumed to be first choice system). Fuel economy changes of -8 to +7 percent as in table DB-2 are expected by D-B. Both systems have demonstrated the 1978 level on experimental vehicles at low mileage.

Other Systems

D-B has experimented with turbochargers on gasoline engines. They report reductions in all three pollutant with improved fuel economy at comparable power; however no marketing intention was disclosed. Also a stratified charge engine was briefly discussed. No operational details were disclosed, and development appears to be in early stages as no CVS tests have been run.

---

* The durability car was above the 1977 levels

A pressure wave supercharger for the Diesel called the "Comprex" system manufactured by BBC was also discussed. Essentially, intake air is compressed by a pressure wave created by exposing the intake air in a tube to high pressure exhaust gas on one end of the tube. At the proper time with respect to the pressure wave, the other end of the tube is opened to the inlet system and the compressed air charge is released. Then the tube is purged of exhaust gas by ambient air and the cycle is repeated. Other tubes or cells are connected in a squirrel cage arrangement and are belt driven by the crankshaft. CVS results were not obtained with this system due to Comprex choking from back pressure created by the CVS system. D-B did not express intentions to market this item either. This system was of interest in that boost pressures obtained were significantly higher than those of conventional turbochargers.

7.3.4.2 Durability Testing Programs

Durability Testing Programs - 1977 Model Year

For the .41 HC, 3.4 CO, 2.0 NOx level, D-B has had consistent success meeting the 2.0 NOx level. However, the D-B experience at complying with the HC and CO requirements has been unsuccessful with the exception of their Diesel models. The principle problem appears to be lack of catalyst durability. This explains D-B's procedure of resorting to a catalyst replacement. Durability testing data for 1974 does not indicate a significant improvement in catalyst durability.

Durability Testing Programs - 1978 Model Year

No data were reported.

7.3.4.3 Progress and Problem Areas

Progress and Problems - 1976 Model Year

D-B has made progress in the last year or so in the area of oxidation catalyst performance at the interim levels. The catalyst changes expected by D-B for most models only were actually required on the 240 gasoline engine for California. Other models do not require a catalyst change. Since the standards are the same for 1976, D-B could use carryover for all models, but because they are introducing K-Jetronic on the 276 cubic inch gasoline engine, they will have to certify this new system.

Progress and Problems - 1977 Model Year

D-B has been successful enough in their Diesel engine development that their 1975 Diesel vehicles have already certified below the 1977 standards. D-B intends to use carryover for 1976 and 1977 on these vehicles. D-B is apparently not just sitting on their hands in the Diesel engine development area, however. The D-B status report contains two areas in which progress has been made. The first area is the development work on boosted Diesel engines. D-B has experimented with both the Comprex supercharger (developed by Brown-Boveri) and with exhaust gas driven turbochargers. The Comprex development has resulted in a Diesel engine with the same power output as a naturally-aspirated gasoline engine of equal displacement. The report team considers this a significant accomplishment, since the specific power output for Diesels has up until now always been below that of gasoline engines. No CVS tests were reported with this setup, due to CVS backpressure problems, according to D-B. The turbocharger work has paralleled the Comprex development and D-B has run CVS tests that show improvements in the HC, CO and fuel economy, with no change in NOx, however, the actual results were not reported. D-B considers the turbocharger to be superior to the Comprex at this stage of development.

The second area in which progress has been made with Diesels is in the development of a V-8 Diesel engine. D-B reported data that indicates that a 276 cubic inch Diesel engine is currently under development. Introduction of such an engine would give D-B essentially two lines of vehicles, one gasoline, one Diesel. D-B currently has a 2.4 litre gasoline and Diesel vehicle, a 2.8 gasoline and 3.0 litre Diesel vehicles, and a 4.5 litre gasoline-engined vehicle. D-B reported only four cold-start CVS tests with the 450D all over the 1977 levels, but the report team is confident that D-B can certify this type of vehicle at the 1977 standards with further work. The fuel economy of the 450D is about 20 miles per gallon on the 1975 FTP, compared to about 10 miles per gallon for the gasoline-engined 450 1977 research vehicle.

Another area in which development has been continued at D-B is the continued work on the 417 cubic inch gasoline engine. The 6.9 litre V8 has reportedly been delayed due to the energy crisis, but D-B apparently is considering it for introduction in 1976 or 1977. Low mileage emissions have been below the 1977 levels, and the fuel economy is in the 8 to 9 mpg range.

One interesting development was not discussed much by D-B. This involves the use of a start catalyst. A vehicle with such a system was reported to be under devleopment, and the specific emission results for that vehicle indicated good control of HC and CO on D-B's largest engine, the 6.9 litre V-8.

TABLE DB-1

FIRST COST OF 76/77/78 EMISSION CONTROL SYSTEMS

Model / Value added for	L4D	L5D	L4		L6		V8	
	240 D	300 D	230		280/C	280 S	450 SE/L	450 SL/C
	50 States	50 States	Cal.	Fed.	50 States	50 States	50 States	50 States
1975 (breakdown see Fig. V A1)	5	6	450	252	409	389	422	455
1976 (estimate over 1975)	-	-	-	-	-	-	- 33^{1} + 12^{2} - 8^{3} - 29	- 33^{1} + 12^{2} - 8^{3} - 29
1977 (estimate over 1976)	+ 64^{4}	+ 18^{5}	+ 31^{6} - 8^{3} + 22		+ 140^{1} + 12^{2} + 49^{6} - 8^{3} + 193	+ 140^{1} + 12^{2} + 49^{6} - 8^{3} + 193	+ 63^{6}	+ 63^{6}
1978 (estimate over 1977)	will not meet 0.4 g/mile NO_x		+ 156^{7} + 20^{8} + 176		+ 217^{7} + 20^{8} + 237	+ 217^{7} + 20^{8} + 237	+ 313^{7} + 30^{8} + 343	+ 313^{7} + 30^{8} + 343
total value added for 1978 em.control	-	-	648		839	819	799	832

Explanation of Footnotes 1 - 8 please refer to Section V A 2, page 3

Cost in US $, 1 $ = DM 2,60, cost basis July 1974

TABLE DB-2

1975 FTP FUEL ECONOMY COMPARISONS FOR DAIMLER-BENZ

Model	1974	1975** Fuel Economy	1975** % Change from 1974	1976* Fuel Economy	1976* % Change from 1974	1977* Fuel Economy	1977* % Change from 1974	1978* Fuel Economy	1978* % Change from 1974
240D		24.1		24		24			
300D		23.9		24		24			
230 Cal	14.2	15.8	+11%	16	+13%	15	+6%	14	-1%
230 Fed	14.2	16.8	+18%	17	+20%	15	+6%	14	-1%
280/C/S	14.2	14.5	+2%	14	-1%	14	-1%	13	-8%
450 SE/L	10.6	11.4	+8%	12	+13%	11	+4%	10	-6%
450 SL/C	10.3	11.5	+12%	13	+26%	12	+17%	11	+7%

* from D-B

** from certification (1974 fuel economy is corrected to 1975 test procedure)

D-B's major problem for model year 1977 is maintaining high conversion efficiency at mileage with their catalyst-equipped gasoline-engined vehicles. To data D-B reported that they have not chosen a specific catalyst as yet. This is D-B's major problem even though the California 240 gasoline and six cylinder California gasoline data vehicles* certified below the 1977 standards in 1975.

Progress and Problems - 1978 Model Year

D-B may have made progress in system testing at low mileage for the 0.41 HC, 3.4 CO, 0.4 NOx level. They, unlike most manufacturers, appear to have tested the GEM 68 catalyst, but the D-B status report was vague as to the existence of the oxygen getter upstream. Other D-B systems including 3-way and other dual catalyst systems have also been tested.

D-B's major problem at the 0.4 NOx level is lack of durability testing. D-B has no vehicles on durability targeted toward 0.4 NOx. D-B also claimed that all Diesels would be dropped for 1978 because 0.4 NOx cannot be met with the Diesel, in D-B's opinion. This is D-B's official position, but in the opinion of the report team, D-B has the capability to achieve 0.41 HC, 3.4 CO, 0.4 NOx with a Diesel. Results lower than the 1978 levels were reported previously by D-B, but D-B will only continue the required development if they feel that 0.4 NOx will be enforced, which apparently they do not.

D-B's opinions on the NOx level achieveable with a stratified charge engine are somewhat out of date. They claimed that no stratified charge engine could get 0.4 NOx because a NOx catalyst could not be used, but the Texaco and the PROCO engine can get to 0.4 NOx with EGR only, which is public knowledge. Also the CVCC data from Honda showing levels below 0.4 NOx is well-known.

---

* The durability cars were above the 1977 levels

7.3.5 Fiat

7.3.5.1 Systems to be Used

Systems to be Used - 1976 Model Year

The 1976 Fiat control systems are identical to their 1975 systems. The 49-states systems include AIR, spark delay valves, decel modulation, and ignition controlled idle fuel shut off on the 79 CID L-4; and the previous system plus vacuum modulated EGR on the 107 CID L-4. These are some of the most unsophisticated systems in use today and compromise fuel economy for initial cost benefits in the opinion of the report team. The California systems are identical to the 49-states systems except that the use of the idle fuel shut off is extended to prolonged decelerations (shut off after decel modulator function is complete) and a UOP oxidation catalyst is added. The pellet-type catalyst is loaded with .03 troy ounces of platinum.

The Fiat initial cost increase estimates were 12.5% and 17% of the cost of the corresponding European versions for the 49-states and California versions respectively. Catalyst replacement is scheduled for 1975 at 25,000 miles, but replacement cost was not stated. The 1975 Fiats are not certified as yet; however, Fiat tests indicate improved fuel consumption from 1974 to 1975 with more improvement possible for 1976. Most models have increased inertia weight for 1975.

Table Fiat-1

Fiat Fuel Economy Comparisons

Model	1974	1975*	% Change From 1974
Federal 128 Sedan, 4dr.	18.2	18.8	+3
Federal Spider 1800	18.8	19.0	+1
Federal Coupe 1800	16.7	17.8	+11
Federal X 1/9	21.3	18.0	-15

* From Fiat

Systems to be Used - 1977 Model Year

The Fiat system to meet the .41 HC, 3.4 CO, 2.0 NOx standard was not directly stated; however, it was implied that the 1976 California system is the basic system for 1977. Fiat would like to eliminate the use of EGR if possible. The report team believes that Fiat should develop more sophisticated EGR systems instead of trying to eliminate EGR so that Fiat could more effectively optimize for fuel economy.

Initial cost of emission control systems was estimated to be 20% of the vehicle cost. Maintenance cost and fuel economy estimates were not available at this control level. Although Fiat has achieved the 1977 levels at low mileage, they have presented data which indicates a rather unique deviation from others in the auto industry in that Fiat is still having problems with all three pollutants at the 1977 levels.

Systems to be Used - 1978 Model Year

To meet the 0.41 HC, 3.4 CO, 0.4 NOx Fiat plans to use a dual catalyst system with secondary AIR in conjunction with the basic 1976 California system. Use of the pellet oxidation catalyst is to be continued, and the reduction catalyst is to be a monolith.

Initial cost of these emission control systems was estimated to be 25% of the vehicle cost. Fiat has reported only a very few successes at the 1978 level. These successful tests were reported in early 1972. Thus it is the opinion of the report team that Fiat needs to devote far more time to systems development and testing.

Other Systems for the Post - 1978 Time frame

Fiat has reported efforts, but no data in the areas of pre-chamber stratified charge, Diesel, gas turbine, and Rankine cycle engines. The stratified charge program is just beyond the single cylinder stage. Five pre-chamber Diesel engine prototypes have been installed in vehicles and parameter studies will be made. A dual shaft prototype gas turbine has undergone stationary testing. It has dual ceramic regenerators, variable power turbine geometry, and a clutch between the power turbine and compressor shaft. A turbine engine component development program is in progress. A second turbine is to be vehicle tested later. The Rankine cycle engine project has been deemphasized due to fuel economy considerations.

Two electric cars have been built. They are conventional Fiats with 10 KW alternating current motors. A hybrid bus using the electric motor and gas turbine may be built in the more distant future.

Also electronic and electro-mechanical fuel injection have been applied to conventional gasoline engines. They are not described; however, one electro-mechanical system was said to be controlled by a mini-computer, and is currently in a vehicle under dyno testing. No emissions data were submitted.

7.3.5.2 Durability Testing Programs

Durability Testing Programs - 1977 Model Year

At the .41 HC, 3.4 CO, 2.0 NOx level Fiat reported durability testing results for 14 vehicles. None of the vehicles achieved this emission level for a significant number of miles. Fiat is having more problems with HC and CO than with NOx.

Durability Testing Programs - 1978 Model Year

Fiat reported one durability test for a vehicle targeted at .41 HC, 3.4 CO, 0.4 NOx. This vehicle did not meet the HC and CO limits at any point but it did comply with the NOx limit for approximately 5000 miles. This vehicle was equipped with a variation of their .41 HC, 3.4 CO, 2.0 NOx level installation with the addition of EGR and a NOx catalyst.

7.3.5.3 Progress and Problem Areas

Progress and Problems - 1976 Model Year

At the time of the preparation of this report, Fiat had not yet finished certification for model year 1975, although it appears that they will be able to certify at the interim levels. One of Fiat's problems, compared to most manufacturers, is that a catalyst change is required at 25,000 miles. This indicates to the report that Fiat's capability with catalysts lags many manufacturers. Fiat does, however, plan to try to go 50,000 miles with no catalyst change for model year 1976, by using a slightly larger catalyst and the experience gained in 1975 certification. Some improvements in fuel economy may be possible for Fiat in 1976 if their design philosophy can be modified somewhat from the current one which uses spark retard extensively.

Progress and Problems - 1977 Model Year

Fiat did not report much data on systems specifically targeted toward 0.41 HC, 3.4 CO, 2.0 NOx. The report team estimates that Fiat will rely heavily on the experience gained during 1975 and 1976 certification for development knowledge for model year 1977. The most significant problem for Fiat is lack of adequate high mileage catalyst efficiency.

Another problem for Fiat may be design emphasis. The report team feels that Fiat is very keen on the design and use of emission control system modulating devices. An example of this is the extensive program reported by Fiat on the development of a catalyst bypass system. This type of system was under development by several manufacturers, but most have dropped it because the systems generally are complicated and expensive and most manufacturers feel that the time response of such systems is too slow to prevent many types of catalyst damage. In the opinion of the report team, Fiat would be a lot better off if they directed their efforts to the design and development of systems that control emissions all of the time, making the necessary improvements to the ignition and fuel metering systems that are required, rather than designing systems that work just well enough to get by on the test.

Progress and Problems - 1978 Model Year

Fiat has had problems just meeting the 0.41 HC, 3.4 CO, 0.4 NOx levels even at low mileage. Other problems for Fiat are the lack of development and testing of the most recent NOx catalyst systems.

The 1978 levels may also be difficult for Fiat to attain with the alternate engines under development. Although Fiat claimed that their Diesel engine was equivalent to existing divided chamber engines, this would put it about 1.0-1.5 NOx and Fiat reported no data on any NOx reduction program for the Diesel.

7.3.6 Honda

7.3.6.1 Systems to be Used

Systems to be Used - 1976 Model Year

The 1976 Honda 49-State system will be the same as the 1975 49-State system. That is a conventional 1.2 litre engine with AIR and calibration changes added to the 1974 system. Initial cost will be about $70.00 over 1974 due to those changes. The 1976 California system was stated to be identical to the 1975 California 1.5 litre (90.8 CID) CVCC (Compound Vortex Controlled Combustion) stratified charge engine. At least partial exhaust after-treatment is accomplished in the stainless steel lined exhaust manifolds. Recalibrations may be made to improve fuel economy. Initial cost increase will be about $160.00 over the 1974 conventional engine.

Despite successful certification of the conventional 1.2 litre (75.5 CID) engine, it cannot be sold in California due to high CO emissions (over 9 gm/mile) of the corresponding durability vehicle which resulted in line crossing. All emissions values in table HO-1 include deterioration.

Table HO-1

1975 Certification Comparison of the 1.5 Litre CVCC versus the 1.2 Litre Conventional Engine with AIR

	CVCC					Conventional Engine				
Transmission	Emissions			Fuel Economy		Emissions			Fuel Economy	
	HC	CO	NOx	City	Highway	HC	CO	NOx	City	Highway
2A	.518	4.80	1.52	24	29	.663	6.77	1.85	25	31
2A	.506	4.28	1.35	23	28	.557	5.23	1.96	24	29
4M	.556	4.34	1.26	28	38	.812	6.67	1.40	28	40

Systems to be Used - 1977 Model Year

The 1977 Honda system will be the 1.5 litre CVCC engine developed for the 1975 statutory standards. Changes from the 1976 California CVCC include calibration changes and a lower compression ratio. Average emissions from a 38 vehicle sample are .23 HC, 2.24 CO, and 1.15 NOx. Average fuel economy was 25.2 mpg over the city driving cycle. Also 33-34 mpg was indicated by Honda over the highway driving cycle. The previous sample vehicles all used the 4 speed manual transmission. No increase in initial or maintenance cost over the 1976 California CVCC is expected, and the fuel penalty is 10% over the 1976 California CVCC according to Honda.

Systems to be Used - 1978 Model Year

In 1978 Honda plans to use a 2.0 litre CVCC with either leaner mixtures and no EGR or EGR. EGR may be used in either the pre-chamber or in the main chamber. Early evidence indicates that if EGR is used, it should be introduced into the pre-chamber. No new data was presented at the 1978 emissions level, thus that it is assumed that no further attempts have been made to optimize fuel economy with EGR. In 1973 Honda indicated capability at this emissions level with twenty-two tests on three vehicles which averaged .294 HC, 2.65 CO, and .297 NOx at 18.0 mpg and ten tests on another vehicle which averaged .325 HC, 2.976 CO, and 0.383 NOx at 19 mpg over the 1975 FTP.

7.3.6.2 Durability Testing Programs

Durability Testing Programs - 1977 Model Year

At the .41 HC, 3.4 CO, 2.0 NOx level, Honda has successfully completed 50,000 mile durability tests on two vehicles. These vehicles were Civic models equipped with 90 CID CVCC engines. No significant failures were reported and the emission levels remained below the goal.

Durability Testing Programs - 1978 Model Year

Honda did not report any testing during this past year for systems targeted at the .41 HC, 3.4 CO, 0.4 NOx level. However, Honda has previously demonstrated stable performance for the CVCC at this level, and Honda has stated that no problems are foreseen in maintaining the emission results at high mileage, with CVCC engines. Typical DF's for CVCC vehicles are less than 1.1.

7.3.6.3 Progress and Problem Areas

Honda does not have any major problems meeting any future emission level. The problems that exist for Honda at the 0.41 HC, 3.4 CO, 2.0 NOx level and the 0.41 HC, 3.4 CO, 0.4 NOx level are to minimize the driveability and fuel economy penalties that have been associated with meeting those levels with prototype vehicles.

Honda continues, therefore to work on improvements to their lean reactor for improved HC control which will allow more spark advance for better fuel economy at the 0.41 HC, 3.4 CO, 2.0 NOx level, a level which they have already been below with durability cars for 50,000 miles.

At the 0.4 NOx level, Honda continues to investigate EGR approaches. One of the problems for Honda is that the EGR approach that gives lowest fuel consumption penalty increases HC and CO greatly (possibly beyond the cleanup capability of their reactor) and Honda does not want to use catalysts.

Honda's emphasis on fuel economy is heightened by their position as fuel economy leader in the U.S. market. They were the best in 1974 and they tied for best in 1975. The report team is sure that Honda will do all that is necessary to remain number one in fuel economy, and that their capability to do so is excellent.

7.3.7. Isuzu Motors Ltd.

7.3.7.1. Systems to be Used

Systems to be Used - 1976 Model Year

Isuzu is the maker of the Chevrolet "LUV" and a new small sedan line for 1976 introduction. Their emission control system for the 49-states includes AIR, ported EGR, heated intake air, and an electric assist choke.

The EGR system will replace transmission controlled spark (TCS) as a NOx control. The compression ratio has been increased and the wedge combustion chamber has been replaced by a hemispherical chamber. The 1976 California model is nearly identical to the 49 state version with an oxidation catalyst and catalyst protection system added. The catalyst is the 160 CID pellet catalyst from AC Spark Plug. When the catalyst temperature reaches 1350°F, secondary AIR is dumped to the atmosphere. If the catalyst temperature reaches 1830°F an operator warning light and buzzer are actuated.

Initial cost of all emissions related hardware on the 1976 Federal models will be $146. The 1976 California system will cost about $219 more than the Federal system. Precertification data indicate that fuel economy will be improved about 7% for the Federal vehicles and 5% for the California vehicles over 1974 models. Emissions of the California version at low mileage were far below 1977 levels at 0.2 HC, 1.4 CO, 1.1 NOx.

Systems to be Used - 1977 Model Year

The final selection of systems for .41 HC, 3.4 CO, 2.0 NOx has not been made. An oxidation catalyst will probably be used, and additional hardware may include backpressure EGR, AIR, exhaust port liners, improved intake and exhaust manifolds, and high energy ignition. The improved intake manifold will provide improved distribution and possibly early fuel evaporation (EFE). The air system may be modulated; however, the system description was too inadequate for proper evaluation. In the opinion of the report team, modulated AIR systems are promising components at .41 HC, 3.4 CO levels.

Early durability vehicles appeared to be inadequate especially for HC durability; however none of the systems had initial HC levels as low as the .2 HC reported for the final calibration of the 1976 California models. The report team hopes that EFE is adopted by Isuzu as further HC and fuel economy benefits could be realized.

The improved exhaust manifold was not described; however it may be related to the renewed Isuzu interest in thermal reactors. Their thermal reactor is called "quasi-stoichiometric" as it operates near stoichiometric A/F ratios. Early results of this system were .42 HC, 6.03 CO, 1.56 NOx, and 21.0 mpg. Supposedly this system is aimed at the 1976 California levels of .9 HC, 9. CO, 2. NOx; however, the 1976 California system will not include the thermal reactor. The fuel penalty of only 5% over the 1976 Federal model is respectable for a thermal reactor system in the opinion of the report team. This system approaches the Peugeot thermal reactor concept; however, Peugeot has demonstrated better emission results.

The 1977 system is expected to cost $65 more than the 1976 California catalyst vehicles. This cost increase is primarily for AIR system modifications and high energy ignition. Fuel economy was stated to be 21.3 mpg, though no supporting data was provided.

Systems to be Used - 1978 Model Year

Two systems are being considered for use at the .41 HC, 3.4 CO, 0.4 NOx level. A dual catalyst system utilizes a monolithic reduction catalyst and a beaded oxidation catalyst in conjunction with switching AIR, EGR, and TCS. The reduction catalyst is used for oxidation during warm up. The EGR system was ported, and the AIR system was not modulated; however it is assumed that the modulated AIR and backpressure EGR systems could be utilized. A 3-way catalyst system was described which used EGR and closed loop electric fuel injection. The system components were not further described. Decel fuel cut off has been achieved. Reported data indicates that only the dual catalyst system at low mileage has achieved the 1978 levels.

Initial cost of the dual catalyst system was estimated to be $197 over the 1977 vehicle. The 3-way system was estimated to cost $774 more than the 1977 system. Electronic fuel injection accounted for $557 of the $774. Fuel economy was stated for only one dual catalyst vehicle test. It was 17.4 mpg at zero miles.

Other Systems

An agreement has been made with Honda for CVCC engine development. A prototype [illegible]s completed in July 1974. No data was submitted.

A 119 CID Diesel prototype with the Ricardo Comet combustion chamber has been built. Reported early results were .59 HC, 1.45 CO, 1.53 NOx, 30 mpg at 2750 lb. inertia weight.

7.3. .2. Durability Testing Programs

Durability Testing Programs - 1976 Model Year

Isuzu light duty trucks have accumulated 5,000 miles of official durability testing. Approval has been granted to start durability testing of two other light duty automobiles. Official durability in 1975 and catalyst durability tests at Isuzu indicate that no problems should be encountered in either Federal or California certification.

Durability Testing Programs - 1977 and 1978 Model Years

Durability testing of early 1977 prototype systems using the 160 CID pellet converter indicate that further system improvements are needed, especially for HC control. No durability testing has been run at the .41 HC, 3.4 CO, .4 NOx level. Problems with low mileage achievement of the 1978 levels apparently have prohibited mileage accumulation.

7.3.7.3 Progress and Problem Areas

Progress and Problems - 1976 Model Year

Previous 1975 certification, low mileage data, and 1977 durability indicate that no problems should be encountered by Isuzu in 1976 certification.

Progress and Problems - 1977 Model Year

The emission durability problem of early 1977 systems indicates that either feedgas or catalyst improvements must be made. Catalyst improvements depend on the progress of related GM programs. Improvements in feedgas levels should be realized with the use of EFE, modulated AIR, or thermal reactors.

Progress and Problems - 1978 Model Year

Efforts at the .41 HC, 3.4 CO, .4 NOx level must be increased. Although Isuzu did achieve these levels at low mileage in 1974 with dual catalyst systems, those systems failed to be durable. The CVCC and 3-way catalyst programs are progressing very slowly and should be more rapidly continued in the opinion of the report team.

Table IZ-1

1975 FTP Fuel Economy of Various Isuzu Models

1974*	1975 Federal	% Change from 1974	1975 Calif.	% Change from 1974	1976 Federal	% Change from 1974	1976 Calif.	% Change from 1974	1977	% Change from 1974	1978	% Change from 1974
20.5	18.7	-9	21.1	+3	22	+7	21.5	+5	21.3[1]	+4	17.4[2]	-15

* corrected from 1974 to 1975 FTP

[1] from Isuzu

[2] from one dual catalyst vehicle

7.3.8 Mitsubishi

7.3.8.1 Systems to be Used

Systems to be Used - 1976 Model Year

The 1976 Mitsubishi (makers of Dodge "Colt") system for the 49-States will be AIR plus EGR as in 1975. The AIR system will be modulated by manifold vacuum and air pump outlet pressure through an air control valve. EGR is nonproportional. Mitsubishi stated that considerable work has been done on a reed valve aspirator system to possibly replace the AIR system in 1976. No vehicle data was presented which used the aspirator system; however, data from other manufacturers with similar systems indicate that aspirators are less effective than AIR systems for emission control. The 1975 carburetor with improved heat resistance and an automatic choke will again be used in 1976.

The 1976 California system will utilize increased EGR, modulated AIR, and a lean thermal reactor as in 1975. EGR is again nonproportional, and the aspirator has not been considered for use in California.

Initial cost increase to the consumer was said to be $229 for the Federal system and $327 for the California system over 1974 models. According to Mitsubishi, the fuel penalty of the 1976 models will be 5-7% for 49-state models and 5-9% for California models over 1974. Maintenance costs are expected to increase by $28 and $31 for the respective models over 1974. These are calculated for a 50,000 mile maintenance interval.

Systems to be Used - 1977 Model Year

The Mitsubishi system for .41 HC, 3.4 CO, 2.0 NOx will include modulated AIR, nonproportional EGR, a pelleted oxidation catalyst, altitude compensated carburetion, and high energy ignition. A proportional EGR system is being developed for improved fuel economy and driveability. The report team hopes that Mitsubishi can have the proportional system for 1977. The catalyst volume is said to be about 45 in^3. Its protection system will consist of a driver warning light which is activated by a fuse near the catalyst. The carburetor will operate lean, have more precise A/F metering, and have an improved automatic choke. This system has demonstrated 1977 levels frequently at low mileage. Development of the AIR, EGR, rich thermal reactor system for 1977 has been suspended.

Initial cost increase to the consumer is estimated to be $95-$120 over 1976 Federal systems. Fuel economy is equivalent to 1975 California models according to Mitsubishi; however, very little actual data was presented. Maintenance costs are to increase by $15 over 1976 models. This increase is due to recommended tail pipe emissions testing. Catalyst change cost at 50,000 miles will be $30-$50.

Systems to be Used - 1978 Model Year

The 1978 Mitsubishi system will include dual catalysts, proportional EGR, switching AIR, high energy ignition, and improved carburetion. The noble metal NOx catalyst will be monolithic, and the oxidation catalyst will be the pellet catalyst used in 1977. The catalyst warning light will monitor both catalysts. The proportional EGR system is not finalized; however, it is to be modulated by venturi vacuum or amplified manifold vacuum. The AIR system is complicated. During warm up, air is injected near the exhaust valves and allows the NOx catalyst to be used as an oxidation catalyst. After light-off of the oxidation catalyst, the air is switched to two locations in the exhaust pipe. The first bleeds modulated air into the reduction catalyst for CO/O_2 ratio control. The second provides modulated air into the oxidation catalyst. The necessary air control valves are not yet available according to Mitsubishi. The carburetor will be similar to the altitude compensated model of 1977. Improvements over the 1977 carburetor will include improved A/F metering and a quicker release choke. Intake manifold heating will be used for the first time. Spark retard will be used only during warm up conditions. Tests of apparently incomplete systems have yielded low mileage results as good as .22 HC, .73 HC, .22 NOx. Development work is beginning on an electronic fuel injection system and an undescribed fluidic controlled fuel system.

Initial cost of the Mitsubishi system for .41 HC, 3.4 CO, and .4 NOx was estimated to be \$77-\$197 over the 1977 system. Maintenance costs are not expected to increase over 1977. The only fuel economy data that was presented again indicated that fuel economy will be equivalent to the 1975 California models. Replacement cost of the oxidation catalyst was \$30-\$35 as in 1977. And replacement cost of the NOx catalyst was said to be \$68-\$184. All stated catalyst replacement costs include labor charges.

Development of the triple catalyst system which yielded .20 HC, 2.85 CO, .25 NOx at low mileage has been suspended "due to its difficulty in production feasibility". It included separate catalysts for NOx reduction, ammonia decomposition, and HC-CO oxidation.

In the opinion of the report team, the lack of proportional EGR and advanced fuel metering systems are unnecessarily hampering Mitsubishi durability efforts at the 1978 levels.

7.3.8.2 Durability Testing Programs

Durability Testing Programs - 1976 Model Year

Since Mitsubishi easily achieved these emission levels in 1975 certification, no problems are expected in 1976. The 1975 Federal vehicles were generally closer to the .9 HC, 9 CO, 2.0 NOx levels of California than they were to the Federal levels. California vehicles frequently had HC levels below .41 gm/mile.

Durability Testing Programs - 1977-1978 Model Year

The most successful of four 1974 durability vehicles at the 1977 levels was vehicle number 203. This was a 97.5 CID Colt with a manual transmission and a control system consisting of AIR, EGR, and an oxidation catalyst. The emissions were .34 HC, 1.94 CO, 1.89 NOx at 38,000 miles though NOx levels had exceeded the 1977 levels as early as zero miles. The 1973 status report contained vehicle #201 which was similar to #203 and achieved .28 HC, 2.13 CO and 1.82 NOx at 60,172 miles with no catalyst change. Previous NOx emission levels had usually exceeded 1977 levels. Vehicle #201 was equipped with AIR and an oxidation catalyst. Vehicle #302 was also in the 1973 status report. It was equipped with AIR and an oxidation catalyst. All emissions were below the 1977 levels up to and including the 20,760 mile test point (.33 HC, 2.20 CO, 1.68 NOx at 20,760 miles). Vehicle #302 was not mentioned in the 1974 status report.

Only one Mitsubishi vehicle has demonstrated the .4 NOx level at 5,000 miles (.40 HC, 3.53 CO, .40 NOx). Even this is impressive when it is considered that improved AIR, EGR, and fuel metering systems are still being developed.

7.3.8.3 Progress and Problem Areas

Progress and Problems - 1976 Model Year

The major problem for Mitsubishi in 1976 is fuel economy. A 5-9% fuel penalty was reported over 1974 models; however, 1976 systems will remain essentially unchanged. Proportional EGR and catalysts could have regained much of that penalty, in the opinion of the report team.

Progress and Problems - 1977 Model Year

Mitsubishi is primarily concerned with catalyst durability in 1977. HC durability failures have been a problem for many pelleted catalyst users. The report team feels that this problem can be eliminated in the case of Mitsubishi with the use of improved cold start HC control techniques. The switch to proportional EGR again would benefit Mitsubishi. The decision to drop the rich thermal reactor system will prevent further fuel economy problems.

Progress and Problems - 1978 Model Year

For 1978 Mitsubishi problems include poor NOx catalyst durability, poor CO/O_2 ratio control into the NOx catalyst, and reduced passenger space due to underfloor catalyst installation. CO/O_2 ratio control will be improved with the electronic fuel injection system. Improved EGR should reduce the burden of the NOx catalyst and help prolong its life. The loss in passenger space should not be too significant.

7.3.9 Nissan (Datsun)

7.3.9.1 Systems to be Used

Systems to be Used - 1976 Model Year

The 1976 49-states Nissan control system is comparable to the 1975 system. It includes heat control, EGR, AIR, decel modulation, simplified EFE, and spark control devices. The transmission controlled spark (TCS) on manual transmission vehicles, spark delay valves (SDV) on automatic transmission vehicles, and less than optimal EGR indicate failure to optimize fully for fuel economy in the opinion of the report team, even though the B-210 was one of the fuel economy leaders.

The 1976 California system is similar to the 49-states system with an altitude compensated carburetor, an oxidation catalyst, and catalyst overtemperature protection system added. The catalyst is an Engelhard noble metal monolith with 0.06 troy ounces of noble metal loading in a 2 to 1 platinum to palladium ratio. Initial cost was originally estimated at $350 - 450 over 1973 and has not been updated. Table NI-1 indicates fuel economy changes from 1974 certification to 1975 certification. The only correction made was for conversion of 1974 fuel economy to 1975 fuel economy due to differences in test procedures. The tendencies of increased engine size and vehicle inertia weight are ignored, thus exaggerating Nissan's losses and reducing their gains in fuel economy.

Systems to be Used - 1977 Model Year

The 1977 Nissan system is similar to the 1976 California system. The catalyst will be larger, and the distributor advance and EGR rate will be recalibrated. Development work has started on proportional EGR and HEI, but they may not be completed for 1977. Initial cost increases are said to be $80 - 150 (over 1975 California) for a larger catalyst only and $140 - 230 for the larger catalyst, HEI, and proportional EGR. Nissan estimated an 11% fuel economy penalty from 1973 which was primarily due to retard. The report team views this estimate as accurate if EGR improvements are not available by 1977. A 1975 710 wagon* attained the 1977 levels in 1975 certification.

Systems to be Used - 1978 Model Year

Nissan has four systems still under consideration for 1978. In descending order of choice, these are a dual catalyst system, a 3-way catalyst system, the Questor Reverter system, and a rich-lean reactor system. The 1978 levels have been achieved at low mileage by the first three preferred systems.

---

* The durability car exceeded 1977 levels

TABLE NI-1
1975 FTP FUEL ECONOMY COMPARISON FOR NISSAN

		1974**	1975		1975 California		1977		1978	
Model	Trans-mission		Fuel Economy	% Change from 1974	Fuel Economy	% Change from 1974	Fuel Economy	% Change from 1974	Fuel Economy	% Change from 1974
Pickup	M4	19.3			19.9*	+ 3				
	A3	21.3			19.6	-8				
710	M4	20.4	21.9	+8	19.9*	-2				
	A3	21.6			18.0	-17				
B210	M4	24.5*	27.4	+12	27.3	+12				
	A3	23.2	24.5	+6	23.2	0				
610	M4	21.0*	20.0	-5						
	A3	20.7	20.1	-3			18.7****	+10	18.6***	-11%
260Z	M4	16.3*								
	A3	16.5								

* two test average
** corrected from 1974 to 1975 FTP
*** 17 test average from 8 vehicles w/mileage from 0-23,800 miles
**** 40 test average from 10 vehicles w/mileage from 0-25,800 miles - are .4 gm/mile NOx target vehicles

The dual catalyst system is similar to the 1977 system with the addition of a reduction catalyst and an AIR switching control. During warm up the air is injected in front of the reduction catalyst to use it as an oxidation catalyst. When warm up is completed, the air is injected after the reduction catalyst and before the oxidation catalyst. The best estimate of fuel penalty is about 11%.

Bosch "L Jetronic" electronic fuel injection (EFI) with a feedback O_2 sensor is used to control the A/F ratio with the 3-way catalyst. A/F ratio must be held at 14.7 (± 1%) according to Nissan. Expected EFI capability is ± 3%. EGR also assists in NOx control.

The Questor system includes AIR and two thermal reactors with a NOx catalyst between the two thermal reactors. Secondary air is introduced into both reactors.

The rich-lean reactor system has two induction systems. The first provides a very rich mixture to half the cylinders and the second provides a very lean mixture to the remaining cylinders. All cylinders exhaust into a thermal reactor. No data was presented for this system.

Other Systems Under Development

Nissan has a stratified charge engine under development similar to the Honda CVCC in principle. It is called the NVCC engine. The following low mileage results in table N-1 have been reported.

TABLE N-1
THE NISSAN NVCC ENGINE

IW	HC	CO	NOx	F.E.	CID
2500	.88-90	5.11-5.45	1.43-1.50	22.3-22.6	108
2750	.28-37	2.9 -3.5	1.15-1.20	17.2-17.6	119

Rotary and Diesel engines are also being studied at Nissan; however neither appears likely to be introduced to the American market within the time frame of this report. The Nissan Diesel, which is sold in Japan, achieved .23 HC, 1.35 CO, and 1.36 NOx with 28 mpg in an uncontrolled state in EPA tests.

Also an on-board fuel distillation system is being developed to eliminate choke operation during cold starts. The system consists of an electrically heated volatile fuel storage tank, additional fuel pumps and solenoids, a coolant temperature sensor, and a modified carburetor. Early test results show 25-30% reductions in CO without catalyst, and 70% reductions in CO without catalysts using highly volatile fuel during warm up.

The Dresser carburetor will also be investigated by Nissan.

7.3.9.2 Durability Testing Programs

Durability Testing Programs - 1977 Model Year

At the .41 HC, 3.4 CO, 2.0 NOx level, Nissan did not report any vehicle durability testing progress since their previous status report.

Durability Testing Programs - 1978 Model Year

At the .41 HC, 3.4 CO, 0.4 NOx level, Nissan had conducted durability testing on six vehicles over the past year. Four of these were equipped with dual catalyst systems and two were equipped with three way catalyst systems. In general both systems complied with the .41 HC, 3.4 CO, 0.4 NOx requirement at low mileage but system degradation caused emissions to exceed this level on both systems when mileage approached 20,000. The total vehicle durability mileage accumulated on systems of this level has dropped from 186,400 miles reported in the previous reprot to 82,500 reported for the period covered by the current status report.

7.3.9.3 Progress and Problems Areas

Progress and Problems - 1976 Model Year

Nissan indicated that they will attempt to make improvements in fuel economy and driveability for 1976, using the same systems that they used for 1975. However no data was reported that showed how they were going to do it. Nissan also did not indicate if they were going to try to go 50,000 miles without the catalyst maintenance that some models required in 1975.

Progress and Problems - 1977 Model Year

Nissan stated that they had not made a great deal of progress since last year and the report team would tend to agree. No more durability results were reported and Nissan did not indicate that any complete 1977 systems had been tested yet. Nissan has, however, run catalyst volume tests which give some idea of how much extra catalyst volume would be required to make the 1975 California package get below 0.41 HC, 3.4 CO, 2.0 NOx.

Progress and Problems - 1978 Model Year

Nissan continues to evaluate several systems, including dual catalyst, 3-way catalyst and thermal reactor concepts. Tests run during the last year have been unsatisfactory with dual catalyst systems. Nissan reported a failure at 15,600 miles with the promising Gould GEM 68 catalyst. However no data were reported. Nissan included copies of letters between Nissan and Gould about the release of the data. Gould apparently wanted some data so they could try to analyze the failure. No data on the Questor system was reported, just the cover page of a Questor report.

Nissan is also having problems with their 3-way systems including A/F ratio control, shifting of the maximum 3-way efficiency A/F value, quality control with O_2 sensors, O_2 sensor instability at low temperature, and O_2 sensor durability.

7.3.10 Peugeot

7.3.10.1 Systems to be Used

Systems to be Used - 1976 Model Year

Peugeot has not stated what systems will be used on the 1976 gasoline models thus 1975 systems will be reviewed. The 49-State gasoline models are powered by a 120 CID inline four cylinder with AIR and a rich thermal reactor for HC and CO control. The axial flow thermal reactor is mounted after the exhaust manifold. The outer shell is stainless steel and the inner shell is Inconel 600. Two single barrel Solex carburetors provide fuel metering. Choke control is manual, but has a coolant controlled device which deactivates the choke should the driver fail to do so. California models are identical except for the addition of the "Coppolair" device which is a decel modulator.

Initial cost increases were stated to be $135 and $186 for the respective Federal and California models over 1973 models. Recent 1975 certification results indicate no change in fuel economy for the four speed wagon and an improvement in fuel economy of the automatic sedan.

Peugeot will also offer the 504 Diesel models in all 50 States with a 129 CID engine. Advanced emission control systems are not needed, but some fuel injection system modifications were made in 1975. These include retarded injection timing, injectors with reduced lift and increased delivery, and the addition of non-return valves in the fuel lines, all for improved HC control.

Systems to be Used - 1977 Model Year

Peugeot has two systems under consideration for use on 1977 gasoline models. Both systems have achieved the 1977 levels at low mileage. The first choice system for the 120 CID engine includes AIR, EGR, the "Coppolair" device, and an oxidation catalyst with an over-temperature bypass system. A final catalyst selection has not been made, and both monolithic and pellet type catalysts are still under consideration. A catalyst change may be necessary at 25,000 miles. The dual single barrel carburetors will be replaced by one single barrel carburetor with altitude compensation. The intake manifold also has been revised for improved distribution. The second choice system is identical to the first choice system except that a thermal reactor replaces the catalyst and its related protection system. In the opinion of the report team, Peugeot is one of the leaders in thermal reactor technology. Their consistent achievement of the .41 HC, 3.4 CO levels with thermal reactors is considered an important technological accomplishment.

Initial cost increases over 1973 were stated to be $660 for the first choice system and $490 for the second choice systems. Changes in fuel economy are indicated in table PE-1.

In the opinion of the report team, durability HC problems of the first choice system could be alleviated with more effort directed toward the cold start portion of the FTP. Catalyst location is poor for rapid warm up, and exhaust gas is not used for quick heating of the intake manifold.

The 504 Diesel model may use oxidation catalysts at the .41 HC, 3.4 CO, 2.0 NOx level to reduce HC emissions. Peugeot has attained these levels with only fuel injection revisions, but combustion noise levels, which are of great importance at Peugeot, were considered unacceptable. Fuel injection parameters are still being studied to find a non-catalytic solution that is acceptable to Peugeot.

Systems to be Used - 1978 Model Year

Peugeot is considering three systems for use in 1978 on their four cylinder gasoline models. The first choice system includes a reduction catalyst, secondary AIR and oxidation catalyst, a catalyst protection system, and proportional EGR. The noble metal reduction catalyst is to be used as an oxidation catalyst during warm up because of its proximity to the exhaust manifold (.8 meters). The AIR system will include an exhaust temperature modulated bypass to further aid warm up. The oxidation catalyst will be the same as the 1977 catalyst which has not been selected. A reduction catalyst selection has also not been made. The second choice system is the same as the first choice system, but includes a thermal reactor to assist in catalyst warm up in the event that the NOx catalyst cannot be operated as an oxidation catalyst. The third choice system includes proportional EGR, a 3-way catalyst, and catalyst protection systems. Peugeot states that A/F ratio control within a 0.2 A/F ratio range is both necessary and possible with oxygen sensor feedback control to a carburetor. Peugeot "asked a specialized company to adapt on a 504 engine one of those (air-fuel control) devices which can be piloted by the oxygen probe."

Initial cost of the first or second choice system is estimated to be $910 over the 1973 model. The third choice system is estimated to be $760 over 1973. Fuel consumption of the dual catalyst vehicles averaged 18.25 mpg according to Peugeot, but 1978 emission levels were not achieved.

7.3.10.2 Durability Testing Programs

Durability Testing Programs - Post 1976 Model Year

For gasoline engines targeted for the .41 HC, 3.4 CO, 2.0 NOx level, Peugeot reported durability test data for eight vehicles. Five of

Table PE-1

1975 FTP Fuel Economy of Peugeot Gasoline - Fueled Vehicles

					1977		1977	
		1974*	1975	% Change from 1974	Catalyst	% Change from 1974	Thermal Reactor	% Change from 1974
Sedan	A3	17.8	17.0	-4			18.7**	+5
	M4	17.6	19.5	+11	17.6**	0	17.5**	-1

* corrected from 1974 to 1975 FTP

** from Peugeot

these were equipped with the first choice system, i.e. AIR, EGR, "Coppolair" and catalyst, and three with the second choice system (thermal reactor instead of catalyst).

The HC and CO control of the first choice system cars deteriorated excessively and catalyst mechanical problems were also experienced. The mechanical problems were a container failure and a mounting failure. One vehicle has reached 50,000 miles and another vehicle is at 31,000 miles and still running. Testing of the remaining vehicles has stopped.

The three vehicles with second choice systems all experienced thermal reactor failures at relatively low mileages. Peugeot described the failures as a destruction of the inlet core. The highest mileage achieved was 15,900. The emission performance of the system appeared to be good. All three vehicles were under the .41 HC, 3.4 CO, 2.0 NOx level.

Peugeot did not report any durability test data for Diesel engines at the .41 HC, 3.4 CO, 2.0 NOx level.

For gasoline engines at the .41 HC, 3.4 CO, 0.4 NOx level, Peugeot reported test data on four vehicles. These tests were not full system tests but were intended to evaluate the durability of only the reduction catalysts. Peugeot noted the variation in NOx conversion efficiency when a system was run alternately with dual catalysts and then with the reduction catalyst only. This behavior is due to the formation of ammonia in the reduction catalyst and subsequent conversion of it to NOx in the oxidation catalyst. The observed effect is a reduced conversion efficiency with the oxidation catalyst present. Apparently, Peugeot did not understand this phenomenon and they interrupted a valuable test to investigate it.

Peugeot's technique of running systems with only the reduction catalyst yields misleading results because the ammonia is not converted to NOx, over the oxidation catalyst. Thus it appears that three of the four reported tests were of questionable use. The data from the fourth test which used both catalysts showed insufficient control of HC, CO and NOx.

Peugeot did not report any Diesel engine durability testing at the .41 HC, 3.4 CO, 0.4 NOx level.

7.3.10.3 Progress and Problem Areas

Progress and Problems - 1976 Model Year

Peugeot should have no problems with their thermal reactor systems for 1976, since the standards are the same and Peugeot did not indicate that they were going to make major changes in their gasoline engines. Peugeot has made progress in the Diesel area for 1976.

Progress and Problems - 1977 Model Year

More problems than progress exist for Peugeot at the 0.41 HC, 3.4 CO, 2.0 NOx level. Durability is a problem with both catalytic converter and thermal reactor equipped gasoline engines. Diesel development is more favorable, but Peugeot considers the injection system modifications that they have tried that met the 0.41 HC level too noisy. They have experimented with a catalytic converter on the Diesel, which must be a disappointment to them, especially since Daimler-Benz has already met the 0.41 HC, 3.4 CO, 2.0 NOx levels in 1975 with their Diesels without resorting to use of a catalyst.

Progress and Problems - 1978 Model Year

Peugeot is having durability problems at this level. Their effort has been slowed somewhat by the misleading results generated on the NOx catalyst only tests. Peugeot does not feel that the Diesel can make 0.4 NOx.

7.3.11 Renault

7.3.11.1 Systems to be Used

Systems to be Used - 1976 Model Year

Three basic systems will be used by Renault to achieve the 1976 Federal emission levels. The Renault 17 Gordini utilizes Bosch electronic "L-Jetronic" fuel injection and AIR. The Renault 12, 15, and 17TL will use AIR plus an oxidation catalyst or AIR, EGR, and an oxidation catalyst. The AIR system is a typical manifold air injection system with a constant 1.14 drive ratio. The EGR is a venturi vacuum modulated system. All three systems use heated intake air, conventional bimetallic chokes, and conventional breaker point distributors. The carbureted versions may have altitude compensation. The fuel injected Gordini has a higher compression ratio than the other models with the 100.5 CID engines, and it develops 24% more power. California systems will be like the Federal systems except that the fuel injected Gordini will not be sold in California.

The initial cost increase over comparable 1974 European models was estimated at $300 for AIR/ox. cat. models, $375 for AIR/EGR/ox. cat. models and $500 for the EFI/AIR models. Fuel economy of the similar 1975 models indicated that significant gains (up to 33%) in fuel economy would be realized by Federal vehicles equipped with four speed manual transmissions. Fuel economy of automatic transmission equipped vehicles remained about the same as the 1974 vehicles.

Systems to be Used - 1977 Model Year

The Renault system for the .41 HC, 3.4 CO, 2.0 NOx levels will be AIR, EGR, and oxidation catalysts. AIR, EGR, oxidation catalysts are similar to those used in 1976. Electric assist chokes and electronic ignition will be introduced in 1977. The use of EFI on the Gordini will be continued. Carburetion may be altitude compensated, and a decel HC control device may be installed to keep the throttle partially open during deceleration. The EFI system controls decel HC in basically the same fashion as inlet air is allowed to bypass the closed throttle. The use of thermal reactors in 1977 has been ruled out due to poor emission reductions and poor fuel economy. Also pellet catalysts are being studied for possible use. Renault vehicles have frequently achieved the 1977 levels at low mileage. A 1975 emission certification data vehicle achieved .216 HC, .680 CO, 1.19 NOx at 4,000 miles without deterioration. No emission data was provided in the Renault status report that was completed after October of 1973.

Initial cost of 1977 Renault systems is said to be similar to the comparable 1976 systems. Fuel economy and maintenance cost information were not provided by Renault.

Systems to be Used - 1978 Model Year

Three approaches are being considered for use in 1978. Renault favors the 3-way catalyst approach which includes EFI with feedback through an oxygen sensor to electronic fuel injection. AIR and EGR are not used. Carbureted and mechanical fuel injected versions of the 3-way system are also being studied. Another system is the dual catalyst, AIR, and EGR system. A NOx catalyst is in or near the exhaust manifold and followed by an oxidation catalyst further downstream. The AIR system switches to provide air to the NOx catalyst during warm up and air to the oxidation catalyst during warm operation. A more proportional EGR system may be employed. A stratified charge approach is also being considered. Details of the engine were not provided; however, only single cylinder work has been reported. With regard to their stratified charge system Renault stated that 1) post combustion devices will be needed for HC control, 2) the 3.4 CO level will be easily attained, and 3) fuel economy is approximately equivalent to the conventional engine. The Renault dual catalyst and 3-way catalyst systems have both achieved the 1978 levels at low mileage. The 3-way results have been most impressive and include .05 HC, 2.33 CO, .15 NOx and .15 HC, 1.79 CO, .16 NOx, at low mileage.

Fuel economy and cost data were not provided by Renault.

7.3.11.2 Durability Testing Programs

Durability Testing Programs - 1977-1978 Model Year

The current Renault status report does not show any vehicle durability testing for the past two years. This appears to be a neglected area for Renault in the opinion of the report team. Previous years test data shows mixed results for the .41 HC, 3.4 CO, 2.0 NOx level. HC and CO control were good but NOx control was insufficient. Preliminary 1975 model year certification data indicates that two data vehicles* have achieved approximately .40 HC, .58 CO, 2.26 NOx and .29 HC, 1.04 CO, 1.19 NOx with deterioration. No durability data was reported by Renault for the .41 HC, 3.4 CO, 0.4 NOx level.

7.3.11.3 Progress and Problem Areas

Progress and Problems - 1976 Model Year

While Renault had not completed certification for model year 1975 at the time of this report, preliminary data indicate no emission problems and fuel economy improvements over previous years.

---

*durability vehicles exceeded the 1977 levels.

Progress and Problems - 1977 Model Year

As discussed in the systems description, preliminary 1975 model year certification data indicates certain models* will be under the 1977 levels. This is encouraging, but Renault is still lacking proportional EGR, modulated AIR, and early fuel evaporation (EFE) systems. Renault also needs to expand their vehicle durability testing program.

Progress and Problems - 1978 Model Year

Along with the other potential users of the 3-way catalyst Renault must improve oxygen sensor and 3-way catalyst durability. An early leader in 3-way catalyst technology, Renault has, disappointingly, made little recent progress.

---

*The data car was above the 1977 levels.

7.3.12 ROLLS-ROYCE (RR)

7.3.12.1 Systems to be Used

Systems to be Used - 1976 Model Year

RR's policy is to have one 50-state system to meet U.S. requirements so in 1976 they will be making 0.9 HC, 9.0 CO, 2.0 NOx systems only. The system is the same as the 1975 50-state system, electronic ignition, EGR, air injection and a Johnson-Matthey/American Lava catalyst. This package certified at 0.54 HC, 6.81 CO, 1.65 NOx for 1975. Since the fuel economy for the 1975 package was not outstanding even for a 5500 pound IW vehicle (9.0 "city", 12.0 "highway") RR plans to try running changes to the EGR and spark timing to up the fuel economy for 1976. RR's fuel economy is improved in 1975 compared to 1974, however, by about 10 percent. Major changes that would require full certification are not worth it, according to RR.

Systems to be Used - 1977 Model Year

To meet the 0.41 HC, 3.4 CO, 2.0 NOx standards, RR will employ the following:

1. Larger Engine (444 CID vs. 412)
2. New Carburetor (SU HIF 7)
3. Proportional EGR
4. Improved Catalyst

The larger engine has reduced friction and an improved combustion chamber, both of which tend to help the engine-out emissions, according to RR. Operation at a lower BMEP for the same power (larger displacement) helps NOx too, due to lower in-cylinder temperatures. The new carburetor has lower friction bearings and viscosity compensation. The PEGR system is a Rochester Products valve with an Eaton transducer, which gives better fuel economy at the same NOx level than does their current system.

The improved catalyst is the J-M type 12C, also mentioned by British Leyland. Improved efficiency at high mileage is claimed for this catalyst and RR's discussion would indicate that it is slightly improved, but not enough to permit meeting 0.41 HC and 3.4 CO in RR's opinion. This catalyst will be used in a larger size for 1977 with increased air injection rates. Lowest results to date are 0.12 HC, 2.58 CO reported by RR as zero mile results from their 1975 system. A backup system to the first choice system is also under development. This uses a dual exhaust system with a catalyst in each exhaust manifold, instead of the current full flow underfloor unit. This may permit both larger catalyst volumes and a better match between light-off and durability.

Another control system mentioned by RR requires special mention. This is a version of a distiller system developed by Mobil Oil and called the LEF (for Low Emissions Fuel) system. The basic principle of systems of this type is to distill a portion of the fuel of high volatility. This fuel is stored in a separate tank and used only to start the vehicle. Use of a volatile fuel for startup can reduce or eliminate the choke, thereby substantially improving HC and CO emissions during the critical period after the cold start before the catalyst has reached light-off temperature.

RR reported tests run by Mobil of a non-catalyst Daimler-Benz 280 that showed reductions in HC and CO of 35 and 52 percent respectively when LEF was used for 100 seconds on the 1972 FTP.

Results reported by RR of a Daimler-Benz vehicle with an oxidation catalyst showed slightly different results. The CO was dramatically reduced, and the vehicle could start without a choke with excellent driveability but HC emissions went up. Results without LEF were 0.19 HC, 1.65 CO, 2.39 NOx; with LEF 0.26 HC, 0.77 CO, 2.10 NOx were typical results, with the lowest CO being on the test that showed 0.29 HC, 0.48 CO, 2.37 NOx. The overall test program showed HC up 20%, CO down 60%, NOx up 14%

RR results with LEF have been less promising, possibly since they used LEF for 30 seconds only. Their non-catalyst results showed the same trend that the Daimler-Benz results showed with a catalyst, HC and NOx up and CO down.

RR does not feel that they need LEF to meet 0.41 HC, 3.4 CO, 2.0 NOx so they do not plan to use it currently. However, RR feels that the LEF system has potential for use in a) vehicles that may be marginal on CO (as would be the case, they feel, with a CVCC engined RR vehicle) or b) a dual catalyst system.

No fuel economy results were reported with any LEF system. There may be a benefit from the no choke operation, but it must be remembered that some energy has to be used to distill the volatile fuel.

Systems to be Used - Model Year 1978

RR is considering four candidate systems for the 0.41 HC, 3.4 CO, 0.4 NOx levels. The first system uses a Solex 4 bbl carburetor, EFE, PEGR, closed loop modulated air injection and a 3-way catalyst.

The second system uses Bosch L-Jetronic fuel injection with feedback control a 3-way catalyst and PEGR. The third system is a Honda CVCC type pre-chamber gasoline engine with PEGR and an oxidation catalyst if necessary. The fourth system uses the current twin S.U. carburetors, PEGR, and a dual catalyst system, with switched air injection.

The first system requires the closed loop controlled air injection which is still under development by Solex. RR, therefore, is waiting until Solex has some hardware that they can test.

The development of the second system received a severe setback when Bosch told RR that an 8-cylinder L-Jetronic package was not going to be available. This has caused RR to investigate whether or not the K-Jetronic (which will be available in an 8-cylinder version) would be an acceptable substitute. Current system configuration calls for slightly rich operation of the three way catalyst with air injection and a supplementary oxidation catalyst, thus making it a 3-way + OX cat system. RR has just started work on this system, the first objective being to get rid of the oxidation catalyst and air pump if possible.

The CVCC system work has been stopped due to: 1) Inability to project NOx levels below 1.0 gpm at 5500 pound IW, 2) Insufficient lead time and 3) High heat rejection to the coolant from this type engine. RR, however is continuing the testing on the Honda-sized engines and vehicles in case the NOx standards are relaxed or someone else comes up with a breakthrough.

The dual catalyst system is the only one under active development now. NOx catalysts from Johnson-Matthey and ICI have been tried. The best results were 0.74 HC, 3.9 CO, 0.52 NOx with an ICI catalyst. RR, like other manufacturers, mentioned that they thought the catalyst manufacturers had just about quit developing NOx catalysts. According to RR, the catalyst manufacturers see no market and think that the 0.4 NOx standards will be relaxed and are therefore concentrating on 3-way catalyst development.

RR's position on 0.4 NOx is that they feel that it may not be required. They state that 1.0 gpm NOx is the lowest standard that can be achieved with a 5500 pound vehicle and anything below 2.0 NOx will result in a fuel economy penalty.

RR also included in their status report an internal RR report that surveyed the field of near term engine possibilities including conventional engines, stratified charge engines (PROCO, TCCS, CVCC) and Diesel engines. The conclusions of the report were that RR should develop the first three of the four systems now contemplated by RR to meet 0.4 NOx. The PROCO, TCCS and Diesel engines are thought to be "expensive long term projects involving entirely new designs of engine with installation problems whose only merit is improved fuel economy".

The RR report contains RR's own estimates, based on existing data extrapolated to RR's projected 5000 pound IW. The RR estimates show the Diesel to be the clear fuel economy winner, but RR estimates that the best a 5000 pound Diesel could do would be about 1.2 NOx and 15 mpg, down from about 17 mpg at 2.0 NOx. PROCO and TCCS with EGR and oxidation catalysts are estimated to be about 16 mph at 2.0 NOx, 14 mpg at 1.2 NOx and 12 mpg at 0.4 NOx. No other engine types were estimated to be above 12 mpg by RR at any NOx level. Although the report team does not necessarily agree with all of the RR estimates (being somewhat more sanguine about the NOx potential of the Diesel, for example), the RR summary chart is reproduced in this report as an example of one company's careful thinking about advanced powerplants and as an illustration of some of the potential differences among various engine types.

7.3.12.2 Durability Test Programs

The durability data reported by RR was sparse. Data were reported on the 1975 certification testing which gave the certified values of 0.542 HC, 6.81 CO, 1.65 NOx with corresponding DF's of 2.44, 2.31 and 1.0 respectively. The other durability data mentioned were a 10,000 mile test with the improved J-M 12C catalyst. RR indicated that the catalyst efficiency was improved, but no test results were shown from that 10,000 mile test.

7.3.12.3 Progress and Problem Areas

Progress and Problems - 1976 Model Year

Since the Emission Standards are the same, and RR does not plan to recertify, RR does not have any major problems for 1976. The progress that has been made by RR, reflected in their improved fuel economy and reasonably low emissions for 1975/76, has enabled them to use much of the effort that might be expended for 1976 certification toward 1977.

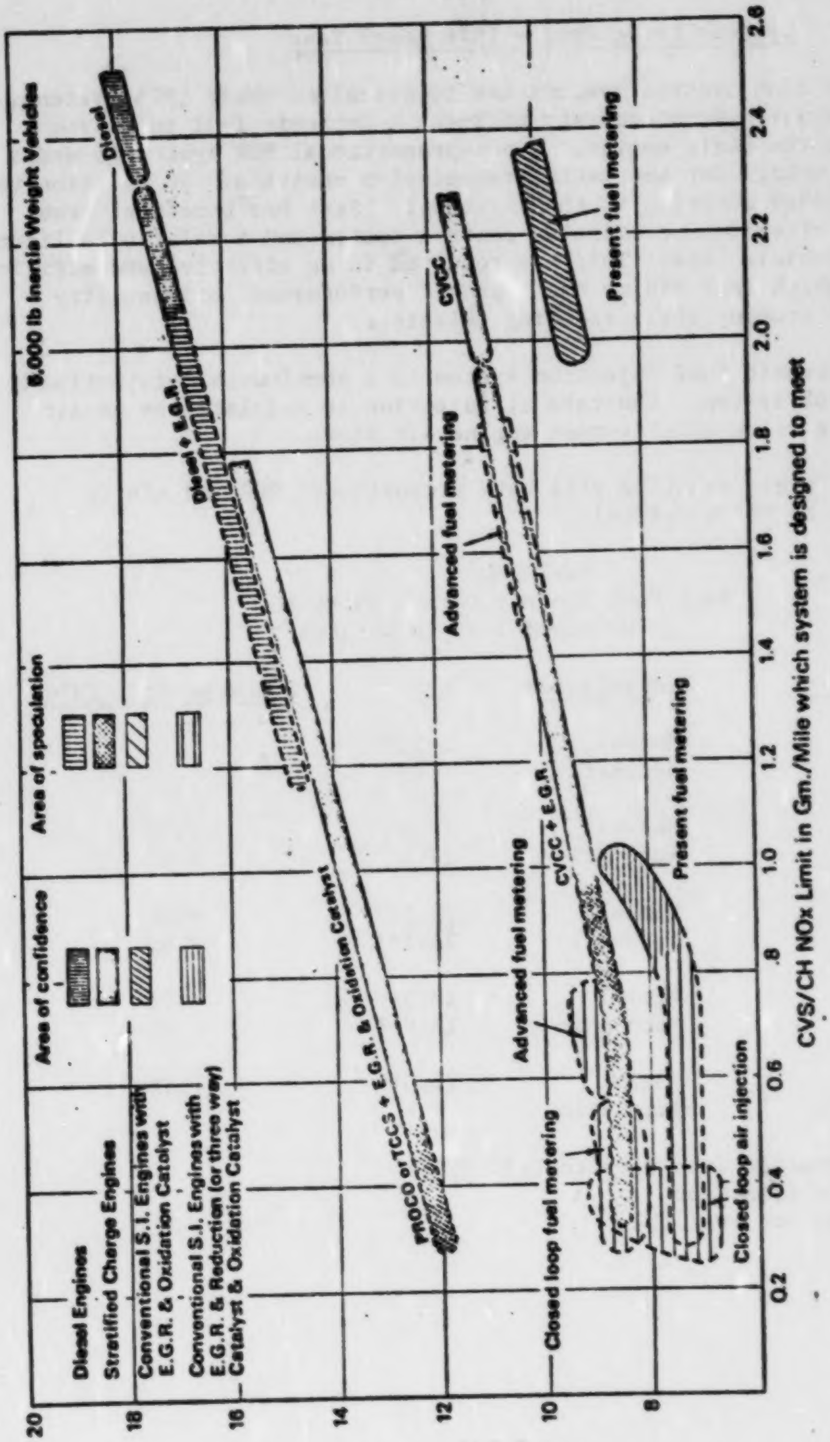
Progress and Problems - 1977 Model Year

RR seems to have made progress in system selection for 1977. The improved oxidation catalyst under consideration by RR appears to have the capability to be a successful 0.41 HC, 3.4 CO, 2.0 NOx system. If the improvement shown by the 12C catalyst at zero miles is maintained over the 50,000 mile durability test RR's chances are good. A serious problem however, in the opinion of the report team, is that RR does not seem to have much durability experience with their improved 1977 system. This is the case for both the prime and backup systems. RR also reported that they were worried about having to meet 1.5 NOx in California for 1977, since they only make 50-State vehicles.

Progress and Problems - 1978 Model Year

RR seems to have covered the field with four possible systems for use in 1978. These systems are much the same as those considered promising by other manufacturers. However, development work on all but the dual catalyst system has stopped. Supplier problems have hurt the carbureted, modulated closed loop air injection, 3-way catalyst system and the fuel injection with feedback, 3-way system. The CVCC system cannot be produced in time for 1978 because development lead time is too short. The lack of supplier support for the first two systems is seen to be another problem for RR. Problems with the dual catalyst system include inability to reach the 0.41 HC, 3.4 CO, 0.4 NOx levels at low mileage, and apparently a total lack of durability testing.

Figure RR-1
(from Rolls-Royce)



Trends in Fuel Economy v NOx Limit for Various Engine Types

7.3.13 Saab

7.3.13.1 Systems to be Used

Systems to be Used - 1976 Model Year

The 1976 Saab control systems are identical to their 1975 systems. The 49 state system consists of Bosch K-Jetronic fuel injection added to the basic engine. A non-proportional EGR system is added to the package for automatic transmission vehicles. In addition to the improved metering of the K-Jetronic, Saab has benefited from careful attention to emission control design and a relatively lightweight vehicle line. This has resulted in an effective and efficient system which Saab claims has improved performance, driveability and fuel economy while reducing emissions.

The K-Jetronic fuel injection system is a continuously injecting mechanical system. The rate of injection is regulated by an air measuring valve which senses engine air flow.

The California vehicles will have proportional EGR and AIR in addition to the K-Jetronic.

Table SA-1
Saab Fuel Economy Data - 49 State
(3000 Pound Inertia Weight)

Model Year	Transmission	MPG	% Change from 1974
1974	Manual	17.8*	
1974	Automatic	16.8*	
1975	Manual	20.8	+17%
1975	Automatic	17.8	+ 6%
1976	Manual	21.1**	+19%
1976	Automatic	21.1**	+26%
1977	Manual	18.5**	+ 4%
1977	Automatic	18.0**	+ 7%
1978	Manual	21.0**	+18%
1978	Automatic	***	

* Corrected from 1974 to 1975 FTP
** Data from Saab
*** Data not available

The table below contains cost information reported by Saab.

Table SA-2
Saab Cost Information

	MODEL YEAR				
	1975-76		1977	1978	
	Fed	Cal		1st Choice	Backup
Added cost to manufacturer	32	81	204	176	309
Sticker price increase	47	120*	306	265	462

* Omitted from Saab data. Calculated using average markup of the other systems.

Systems to be Used - 1977 Model Year

Saab plans to use a monolithic oxidation catalyst in addition to its 1975-1976 California package to comply with .41 HC, 3.4 CO, 2.0 NOx level. Saab previously reported that their first choice was a pelleted catalyst due to unsatisfactory durability of monoliths. Recent test experience has changed their opinion. Since the previous durability problems of monolithic catalysts were experienced almost exclusively with carbureted engines, it appears to tne report team that the adoption of the K-Jetronic precipitated the switch to monoliths.

Systems to be Used - 1978 Model Year

To meet the .41 HC, 3.4 CO, 0.4 NOx level Saab's first choice system will be a 3-way catalyst with an oxygen sensor in addition to the K-Jetronic fuel injection. Their backup system will be dual catalysts combined with AIR and proportional EGR. Saab provided the following test data on a 3-way system.

	HC	CO	NOx
Fresh Catalyst	0.21	3.83	0.61
Aged 220 Hours	0.23	4.10	0.59

Other Systems

Saab reported development progress on an on-board distillation system. This systems allows the engine to be started and warmed up without the use of cold start enrichment. This is accomplished by supplying the engine with the highly volatile light ends of the fuel for the first two minutes of operation. The system includes a boiler/separator which extracts the light ends from the regular fuel and then stores this light fuel in a special tank. Saab furnished the following test data for a 1977 model year system Saab 99:

Table SA-3
Saab On-Board Distillation Fuel System

	HC	CO
1977 system	.25	1.79
1977 system and OBD	.12	.70

Saab reported that this system was acquired through an agreement with Mobil Oil Corporation. While the results are encouraging, Saab reported that they do not plan to proceed further with this system because they have confidence that their existing systems will be sufficient to comply with the future standards.

Another promising cold start aid reported by Saab is electrical heating of the K-Jetronic's fuel nozzles. Saab reported that work is continuing with Bosch on this technique. No test data was furnished by Saab. Another cold start technique utilizing the K-Jetronic is acceleration - enrichment. This technique works similarly to a carburetor's acceleration pump. Saab reports that this technique allows the use of less overall cold enrichment. Apparently the K-Jetronic unit is calibrated for lower baseline cold enrichment and utilizes the acceleration - enrichment to provide enrichment when it is most needed - during acceleration.

7.3.13.2 Durability Testing Programs

Durability Testing Programs - Post 1976 Model Year

At the .41 HC, 3.4 CO, 2.0 NOx level Saab reported durability testing on six cars. Unfortunately, the reported test data contained little high mileage emissions data. The test cars were equipped with AIR, EGR and oxidation catalysts in addition to the K-Jetronic fuel injection. The highest mileage reported was with one car at 32,878 miles with 0.30 HC, 1.44 CO, 1.82 NOx. At the .41 HC, 3.4 CO, 0.4 NOx level, Saab reported that durability testing was about to commence on one car. This vehicle is equipped with a 3-way catalyst system including an oxygen sensor for feedback.

7.3.13.3 Progress and Problem Areas

Progress and Problems - 1976 Model Year

Saab will use the same systems for 1976 as they certified in 1975. Saab's performance in 1975 was a real accomplishment, improving their fuel economy and certifying to both the Federal and California standards with no catalyst. Since Saab used Indolene 30 (leaded fuel) in certification, their performance is a demonstration that the 0.9 HC, 9.0 CO, 2.0 NOx standards do not require the use of catalysts and therefore lead-free fuel, at least for 3000 lb. inertia weight vehicles.

Progress and Problems - 1977 Model Year

Saab has a minor problem in that they recently switched their catalyst choice away from pellets to a monolith, so they don't have as much experience with them as they might like, and their limited durability results show it. Because of their impressive no-catalyst emission levels Saab could almost get by with a hot rock as a catalyst, in the opinion of the report team.

Saab's status report reflects their status at the 0.41 HC, 3.4 CO, 2.0 NOx level. For this year's report we asked manufacturers specifically for information on advanced HC control techniques, since for most manufacturers, HC is going to be the biggest problem at the 0.41 HC, 3.4 CO, 2.0 NOx level, Saab also reported working on advanced HC control techniques such as the Mobil Oil LEF system, but even though Saab's results showed HC and CO reductions of 52 and 46 percent, respectively, Saab does not plan to use the device because they feel their emissions are low enough already.

Progress and Problems - 1978 Model Year

Saab has durability problems with their 3-way system, and the limited low mileage results reported were above the 0.41 HC, 3.4 CO, 0.4 NOx levels. Saab favors the 3-way approach, and no data on their dual catalyst systems was reported. Saab's reported progress with the 3-way approach is somewhat slower than other manufacturers which surprises the report team since Saab has always been one of the leaders in emission control, despite their small size and low U.S. sales volume. Saab should be a big fan of the 3-way approach, in the opinion of the report team, because they, like the leaders in the 3-way field, have already accepted the cost penalty for fuel injection. Part of Saab's less than outstanding results to date with the 3-way approach may be that Bosch is doing a lot of the work for them, and the results may be slow in coming from Bosch to Saab to EPA.

7.3.14 Toyo Kogyo (Mazda)

7.3.14.1 Systems to be Used

Systems to be Used - 1976 Model Year

Toyo Kogyo will continue to market both rotary and reciprocating engines in 1976. In response to the energy crisis TK has embarked upon an extensive development effort to dramatically improve the fuel economy of the rotary, while retaining acceptable emissions The rich thermal reactor has been scrapped and TK will introduce in 1976 a lean thermal reactor system called the "Lean Combustion. System" (LCS). The LCS will include engine modifications, reactor system improvements, secondary air system improvements, and changes to the induction and ignition systems. TK estimates that fuel economy will be improved by 40% compared to 1974 which would give their 2750 pound vehicles about 15 miles per gallon on the city test. TK plans to certify the same type system for both California and the 49 states.

For 1976 model year reciprocating engined models, TK will use different systems for the 77.6 cubic inch and the 96.8 cubic inch engines. Both will use enlarged exhaust manifolds which TK refers to as reaction manifolds. The 77.6 cubic inch engine will also be equipped with proportional EGR and an oxidizing catalyst. The 96.8 cubic inch engine will have air injection along with the reaction manifold.

TK reported that the 77.6 cubic inch engined-vehicles for California will use air injection, proportional EGR and an oxidation catalyst in addition to the reaction exhaust manifold. Two systems are being considered for the California 96.8 cubic inch engine. One system is essentially the same as the smaller engine system. The alternate system would employ a thermal reactor along with vacuum modulated air injection. This alternate system appears to be identical to the original 1975 system which was dropped following the establishment of the interim standards. TK estimates that the fuel economy of the 1976 model year reciprocating engines will be equivalent to the 1974 figures.

Systems to be Used - 1977 Model Year

For their rotary engines at the .41 HC, 3.4 CO, 2.0 NOx level, TK will augment their 1976 LCS package with the addition of proportional EGR and high energy ignition. An alternate system for 1977 will employ fuel injection to achieve a stratified charge. This system, called the ROSCO (Rotary Stratified Combustion)), is based on the LCS and will use a lean thermal reactor. This system utilizes the natural swirl of the rotary engine in combination with a timed injection to create an effective charge stratification. This engine has a potential for improved fuel economy and lower NOx. TK expressed some uncertainty as to the introduction date of the ROSCO, as 1977 and 1978 were alternately cited. TK estimates the fuel economy of both the LCS and ROSCO for the 1977 model year to be equivalent to 1976 rotary engines.

Three alternative systems were reported by TK for the 1977 model year reciprocating engines. The first system is similar to the 1976 California catalyst system except for a change in the inlet port configuration. The new arrangement will induce a swirl to achieve improved combustion. The second alternative system will employ a rich thermal reactor along with a modified secondary air system which both modulates and heats the air. This system also has proportional EGR. The third system for 1977 is a prechamber type stratified charge engine using either an oxidizing catalyst or a lean thermal reactor. TK did not provide fuel economy estimates for these systems, but it was reported that their goal was equivalent or better than 1974.

Systems to be Used - 1978 Model Year

TK reports that a new divided chamber rotary engine is under development for the .41 HC, 3.4 CO, 0.4 NOx level. Called the SCP (Stationary Combustion Process), this engine utilizes lean carburetion to supply the main (rotating) chamber and fuel injection for the separate (stationary) chamber. TK claims that this concept has a strong potential for lower NOx, because of the charge stratification and self EGR in the separated chamber.

Two systems were reported for 1978 model year reciprocating engines. The first utilizes a dual catalyst along with modulated air injection and proportional EGR. The second system would use the prechamber stratified charge engine proposed for the 1977 model year along with proportional EGR and an oxidation catalyst.

7.3.14.2 Durability Testing Programs

Durability Testing Programs - 1976 Model Year

Toyo Kogyo reported durability testing of nineteen 1976 model year rotary engine cars. Fourteen of these were California systems and five were 49 State systems. Three of these cars had accumulated substantial mileage and were safely under the compliance level. The remainder were at low mileage (500-2000 miles). The average reported fuel consumption for the 49 state cars ranged from 15-17 MPG and for the California cars ranged from 14 to 16 MPG. While the test procedure for these fuel consumption figures was not spelled out it is assumed to be the official urban test. If this is the case, TK has scored a major improvement with the lean thermal reactor system.

Durability Testing Programs - 1977 Model Year

At the .41 HC, 3.4 CO, 2.0 NOx level, TK reported durability testing of three cars with rotary engines. Two had the augmented Lean Combustion Systems (LCS-II) and one was equipped with the ROSCO system. The low mileage emission data showed compliance with the 1977 standard except for one of the LCS-II cars being above the NOx level. The fuel economy was reported to be 16 to 17 MPG.

TK reported durability data for three cars equipped with reciprocating engines. All three cars exceeded the 1977 standard at high mileage.

Durability Testing Programs - 1978 Model Year

At the .41 HC, 3.4 CO, 0.4 NOx level, TK is testing three reciprocating engine cars. Two were equipped with dual catalyst systems plus EGR.

No test data were supplied for the dual catalyst cars. The low mileage results for the reciprocating stratified charge engined vehicle were 0.25 HC, 3.5 CO, 0.8 NOx.

TK reported only low mileage test data for two rotary engined vehicles at the 1978 levels. The first vehicle had 0.33 HC, 1.73 CO, 0.38 NOx with 16 mpg, and the second had 0.30 HC, 0.20 CO, 0.58 NOx and 17 mpg.

7.3.14.3 Progress and Problem Areas

Progress and Problems - 1976 Model Year

TK has made significant progress toward the development of systems targeted toward the 1976 interim standards. In constrast to most other manufacturers, who are doing little or nothing extra for 1976 over 1975, TK is revamping their entire emission control development effort. The design criteria have been changed, now fuel economy and emissions are equally important. Emission control was previously the overriding design constraint. This has caused TK to embark on perhaps the most extensive development program to improve both emissions and fuel economy of any manufacturer. The lean system (LCS) for 1976 rotary engines will have improved fuel economy over the 1974 systems, by approximately 40 percent while maintaining emission control to the interim levels. Improvements will also be made with the reciprocating engine, and a smaller size engine may be introduced for 1976. TK feels that the conventional engine with a catalyst is better than a thermal reactor for fuel economy at the 0.9 HC level.

The report team considers TK's major problem for 1976 to be lead time to introduce all of the improvements that are planned.

Progress and Problems - 1977 Model Year

For 1977 TK is showing some of the expertise in rotary engine development that has enabled them to become the world's leader in rotary engines. The technological base that enabled TK to turn the rotary engine from a German curiosity into a viable high-volume production engine is being turned toward meeting the 0.41 HC, 3.4 CO, 2.0 NOx levels with improved fuel economy. TK's approach toward meeting their emission and fuel economy goals is to improve the basic engine as much as possible. This approach is somewhat different than GM's approach with the GM rotary engine. GM has tried many sophisticated aftertreatment devices to try to convert the excessive engine-out HC emissions of their engine and has not been successful. TK's lean thermal reactor and the direct cylinder stratified charge engine are the better technical approaches, in the opinion of the report team.

More problems exist with the reciprocating engine than exist with the rotary engine at the 0.41 HC, 3.4 CO, 2.0 NOx levels. TK is trying to find a better catalyst currently for their 1977 package.

Progress and Problems - 1978 Model Year

TK has also made great progress toward meeting the 1978 standards with the rotary engine. Their prechamber stratified charge rotary has achieved 0.33 HC, 1.73 CO, 0.38 NOx at low mileage, equipped with an oxidation catalyst. The fuel economy is also significantly improved (16 mpg) over the 1974 levels. However, this package has not yet been durability tested.

TK is also considering a new prechamber reciprocating engine for 1978, in addition to their dual catalyst system, although the development is not as far along with the prechamber engine.

A problem for TK at the 0.41 HC, 3.4 CO, 0.4 NOx level may be also common to other years' development programs. Consider the following: completely new lean thermal reactor systems for 1976, improved lean thermal reactors and/or a new direct cylinder fuel injected stratified charge engine in 1977, and a new prechamber stratified charge engine for 1978! This is just for the rotary engine, similar but somewhat less radical changes (until 1978) were also planned for the reciprocating engine.

The report team considers TK's planned efforts to be a larger effort than any other manufacturer, and a problem may be that TK's R&D, tooling, and manufacturing capability might be strained to the limit.

7.3.15 Toyota

7.3.15.1 Systems to be Used

Systems to be Used - 1976 Model Year

Toyota reports that their 1976 model year systems will be unchanged from 1975 with the only exception being the addition of a catalyst or thermal reactor to the light duty trucks for California to comply with the tougher '76 standard there.

For the 49-State standards,Toyota will employ both catalyst and non-catalyst systems. For their two smaller, 4 cylinder engines Toyota will rely on engine modifications, EGR and air injection. The smallest engine will not need EGR to meet the 3.1 gpm NOx standard when installed in the 2500 lb. inertia class Corolla. Their larger, six cylinder, engine family will use AIR, EGR and an oxidation catalyst.

The California vehicles will all employ oxidation catalysts in addition to their 49-State systems.

Systems to be Used - 1977 Model Year

For the .41 HC, 3.4 CO, 2.0 NOx level, Toyota's first choice system will consist of engine modifications, AIR, proportional EGR, reactive exhaust manifold and an oxidation catalyst. For a backup system, Toyota would substitute a full-blown thermal reactor for the reactive manifold. Fuel consumption for 1977 Toyotas is estimated to be equivalent to 1975 for the first choice system and approximately five percent less for the second choice thermal reactor system. Toyota did not furnish any cost data for these systems.

Systems to be Used - 1978 Model Year

At the .41 HC, 3.4 CO, 2.0 NOx level, Toyota's first choice system is a 3-way catalyst in conjunction with Bosch L-Jetronic fuel injection and proportional EGR. Toyota was previously pursuing a dual catalyst system and might switch back if the 3-way does not work out. The fuel economy of the 3-way system should be on the order of a five percent less than achieved with 1974 systems.

7.3.15.2 Durability Testing Program

Durability Testing Program - Post 1975 Model Year

Toyota has extensive experience with systems at and below the .41 HC, 3.4 CO, 2.0 NOx level. Toyota was originally working toward a self-imposed goal of achieving a .41 HC, 3.4 CO, 1.5 NOx level by 1975. For this reason they have an advantage on other manufacturers at this time. Toyota reported 1974 durability test data for 14 vehicles targeted to the .41 HC, 3.4 CO, 2.0 NOx level. Toyota demonstrated consistent success in meeting this level particularly with their P-3 system which consists of engine modifications, air injection, EGR, thermal reactor and a pelletted oxidation catalyst.

Toyota performed durability testing on 17 cars targeted for the .41 HC, 3.4 CO, 0.4 NOx level. However, twelve of these were tested prior to 1974 and, therefore, do not represent the latest technology. None of the cars was able to achieve the 1978 standard level for more than 4000 miles without catalyst replacement. Two of the five cars tested this year had three-way catalyst systems which incorporated the Bosch L-Jetronic fuel metering system.

7.3.15.3 Progress and Problem Areas

Progress and Problems - 1976 Model Year

Toyota plans to use 1976 as a year to improve fuel economy and reliability and to reduce costs. Little detail was provided on how they plan to do this.

Progress and Problems - 1977 Model Year

Toyota stated that there were problems with driveability, packaging, maintenance (catalyst change is contemplated), fuel economy and cost with their 1977 catalytic emission control systems. In the opinion of the report team, Toyota has a good idea of what will be required to certify at 0.41 HC, 3.4 CO, 2.0 NOx since they had targeted for more stringent standards (0.41 HC, 3.4 CO, 1.5 NOx) a long time ago and have much experience at these levels. Much of Toyota's problems at this level are cost related, in the opinion of the report team. Toyota may not want to accept the additional cost inherent in their 1977 system, especially since they reported that the cost of the 1976 car (with no new systems and a cost reduction effort underway) would increase due to inflation alone.

No data was reported on the CVCC engine under development by Toyota under an agreement with Honda, even though this engine was reported to be under development for model year 1975 production for the Japanese market. If this is true, it should be available on some models for the U.S. market by 1977, in the opinion of the report team. Toyota should have the capability to match what Honda has already demonstrated can be done with this engine concept at the 0.41 HC, 3.4 CO, 2.0 NOx level. Toyota has already achieved emissions below the required levels with this concept.

Additionally, no data was specifically reported on the Yamaha concept (see section 7.2.3 - Yamaha). This is somewhat surprising, since Yamaha makes one of Toyota's engines for them and have modified it to achieve emissions below the 0.41 HC, 3.4 CO, 2.0 NOx levels with no catalyst and good fuel economy, with a set of engine modifications that appear to the report team to cost less than $50.

Progress and Problems - 1978 Model Year

Toyota has returned their dual catalyst system to the research stage and like most manufacturers has stopped working on systems targeted toward 0.4 NOx, in the opinion of the report team. Some 3-way work is estimated by us to be actually targeted at a higher NOx level.

7.3.16 Volkswagen

7.3.16.1 Systems to be Used

Systems to be Used - 1976 Model Year

Volkswagen appears to be in a state of flux at this time with regard to 1976 systems. The 1975 systems are being reshuffled and expanded with the result being that models will be available with more than one system. For example, it appears that the Rabbit will be available either carbureted as in 1975 or with the Bosch K-Jetronic fuel injection. A logical explanation for this change would be that the likely improvement in fuel economy resulting from the addition of the K-Jetronic will enhance the sales appeal. Indeed, there is some likelihood that a Rabbit, so-equipped, could achieve that best overall fuel economy of all vehicles tested.

During 1975 model year certification, VW models* representing 51% of the their estimated sales were certified at levels below .41 HC, 3.4 CO, 2.0 NOx (the 1977 standard). All of these were water-cooled engines with EGR, AIR and oxidation catalysts. The catalysts were replaced at 30,000 miles. The cost of the catalyst change was quoted by VW as $177.

Systems to be Used - 1977 Model Year

At the .41 HC, 3.4 CO, 2.0 NOx level, VW reports their first choice system will be fuel injection, EGR and an oxidation catalyst. The air-cooled engines will use L-Jetronic fuel injection and the water-cooled engines will use K-Jetronic. L-Jetronic is an electronic, timed injection system, whereas K-Jetronic is a mechanical, continuous injection system. VW describes the catalyst as "improved/very hot operating". No durability or efficiency data was provided for this new catalyst. For water-cooled engines. VW indicated that another first choice system would be AIR, EGR and an oxidation catalyst in conjunction with carburetion instead of fuel injection. VW estimated that the first two systems would cost five percent more than the 1975 model year systems and would yield equivalent fuel consumption. VW estimated that the third system would be equal in price to 1975 systems but would suffer a five percent fuel economy penalty. The driveability of all three was predicted to be unchanged from 1975. VW indicated that a catalyst change would be still required for all three systems.

---

*durability cars were above the 1977 levels.

Systems to be Used - 1978 Model Year

For the .41 HC, 3.4 CO, 0.4 NOx level, VW reported that their first choice system would be fuel injection, EGR and a 3-way catalyst with oxygen sensor feedback. As with the 1977 model year systems, the air-cooled engines will have the Bosch L-Jetronic unit and the water-cooled engines will have the K-Jetronic unit. VW estimated that the adoption of these systems will result in an 18% cost increase over 1975 models. VW also estimated that fuel economy would decrease by 5 to 8 percent and the driveability would be unchanged.

7.3.16.2 Durability Testing Programs

Volkswagen's current status report provided very little information on durability testing. VW merely stated that the test fleet consisted of 130 vehicles with 20 percent of these running AMA durability, 20 percent "experiments" vehicles and 60 percent in customer type service. Durability and emission data were not reported and no breakdown was made regarding the emission level design goals for the 130 test vehicles.

The 1975 model year certification results provide a measure of reassurance that Volkswagen will be able to comply with the .41 HC, 3.4 CO, 2.0 NOx level. Models representing 51 percent of VW's projected sales, certified at levels below .41 HC, 3.4 CO, 2.0 NOx. In the opinion of the report team this resulted from VW's lack of durability testing prior to the actual certification, which caused VW to overshoot the degree of emission control. All of the models certifying at this low level had undergone a catalyst replacement at 30,000 miles.

7.3.16.3 Progress and Problem Areas

Progress and Problems - 1976 Model Year

Because VW plans to use basically the same systems for 1976 as are used for 1975 no major problems are seen for VW at the 1976 interim levels. Some manufacturers like VW, who relied on a catalyst change to help them meet the standards, are going to try to recertify with no catalyst change for 1976 as they gain confidence and experience with the catalyst approach. However, VW apparently will continue to rely on the customer paying the $177 for the catalyst change at 30,000 miles that their water-cooled engines now require.

Progress and Problems - 1977 Model Year

VW may go with improved catalysts and fuel injection on the 1977 package but little data was provided on the catalyst except that it operated hotter. Since VW has already certified about half* of their model line below the 0.41 HC, 3.4 CO, 2.0 NOx standards (with the catalyst change) they only have to work on the other half if they do not want to make any improvements.

---

*the durability cars were above the 1977 levels.

Progress and Problems - 1978 Model Year

VW apparently will use the 3-way approach to meet the 0.41 HC, 3.4 CO, 0.4 NOx requirements. Little data was provided especially on durability testing of the 3-way package in its latest generation with VW's new vehicles. VW, like other manufacturers apparently has not done much testing at this level recently.

7.3.17 Volvo

7.3.17.1 Systems to be Used

Systems to be Used - 1976 Model Year

The Volvo control system for 1976 will be essentially unchanged from 1975. The 49-State systems for manual transmission cars will consist of breakerless ignition and AIR along with the Bosch K-Jetronic continuous fuel injection. The 49-State automatic transmission vehicles will have non-proportional EGR as well. The 1976 California cars will have Engelhard monolithic oxidation catalysts and proportional EGR in addition to basic 49-State system.

The Bosch K-Jetronic system is a continuous injection, mechanical system (as opposed to the L-Jetronic which is a timed injection, electronic system). The rate of injection for the K-Jetronic is regulated by an air valve which senses engine air flow.

The fuel consumption data in the following table was provided by Volvo.

Table VO-1

Volvo Estimated Fuel Consumption
Based on EPA 55% City 45%
Highway Driving*

Model Year	Transmission	MPG	% change from 1974
1974 Fed	M	20.0	--
1974 Fed	A	21.5	--
1974 Cal	M	21.7	--
1974 Cal	A	22.1	--
1975 Fed	M	20.5	2%
1975 Fed	A	19.5	-9%
1975 Cal	M	20.5	-5%
1975 Cal	A	20.2	-9%
1976 Fed	M	20.1	.5%
1976 Fed	A	19.0	-12%
1977	M	20.0	0%
1977	A	18.9	-12%
1978**	M	18.0	-10%
1978**	A	17.0	-21%
1978***	M	20.4	+2%
1978***	A	19.3	-10%

* Data from Volvo
** Dual bed catalyst and EGR
*** 3-way catalyst and EGR

The estimated cost information shown in the following table was provided by Volvo.

Table VO-2

Estimated Emissions System Cost

Model Year	Cost
1975-1976 Federal	$105
1975-1976 Calif.	$290
1977	$508*
1978	$560*

* Includes $174 for catalyst replacement

Systems to be Used - 1977 Model Year

For the .41 HC, 3.4 CO, 2.0 NOx level, Volvo is planning on using breakerless ignition, AIR, proportional EGR and an Engelhard oxidation catalyst in addition to the K-Jetronic fuel injection. Volvo reported that the system will also be augmented by some combination of the following techniques: fast off lean choke, retarded spark timing and catalyst change. The fast off lean choke is incorporated into the K-Jetronic fuel injection and includes an acceleration enrichment feature which helps maintain good driveability during warm up.* The retarded spark and catalyst change are last resort techniques due to their adverse effects upon fuel economy and cost.

Systems to be Used - 1978 Model Year

At the .41 HC, 3.4 CO, 0.4 NOx level Volvo reports that their first choice system will consist of breakerless ignition, proportional EGR and a 3-way catalyst with oxygen sensor feedback to the K-Jetronic fuel injection. Volvo, working in conjunction with Bosch and Englehard, has made impressive progress in 3-way catalyst technology. High catalyst conversion efficiencies are being maintained up to 1000 hours on bench testing. Volvo's back up system for 1978 is a dual bed catalyst with EGR and AIR.

---

* Volvo reported that the lean choke and acceleration enrichment resulted in CO and HC emissions reductions of 60% and 35% respectively in CVS testing.

Other Systems

Bosch reported a 50% reduction in CO during cold start CVS testing through the use of electrically heated fuel nozzles on the K-Jetronic. This resulted from a further shortened choke period with the fast off lean choke system. Unfortunately, Volvo reports that the associated problems of vapor locking, fouling and clogging of the injectors due to fuel cracking combined with the electrical drain (5 to 10 amp per injector) have caused them to abandon this concept. In the opinion of the report team the fuel cracking problem which results from excessively heating the fuel (above 200°C) could be surmounted by further development effort. The electrical drain could be overcome by a larger capacity battery. The potential benefits of heated fuel nozzles, in the opinion of the report team, justify further development efforts, if more HC and CO control is needed by Volvo in the future.

7.3.17.2 Durability Testing Program

Durability Testing Program - Post 1976 Model Year

At the .41 HC, 3.4 CO, 2.0 NOx level, Volvo reported durability test data on 25 vehicles. Nineteen of these were their first choice '77 system, i.e. AIR, proportional EGR, oxidation catalyst, and Bosch K-Jetronic fuel injection. The remaining six were 3-way catalyst systems calibrated for this level. The first choice '77 system demonstrated consistent success in maintaining this level. The 3-way systems showed very low emissions at zero miles but deterioration of conversion efficiency quickly resulted from drift of the "window". The oxygen sensors were changed frequently to realign the air/fuel ratio to the efficient conversion range. Four of the six 3-way systems have accumulated 50,000 miles and the other two are at 30,000 miles. The best performing system used a Kali Chemie 516-59 3-way catalyst.

Volvo did not report any vehicle data on systems calibrated for the .41 HC, 3.4 CO, 0.4 NOx level. However, the previously described 3-way system testing is laying the groundwork for a 3-way system for this level. Volvo did report impressive progress on dynamometer testing of 3-way systems at this level, with high conversion efficiencies holding nearly constant for up to 800 hours. This would be equivalent to 24,000 miles at an average speed of 30 mph. This system employed an Engelhard advanced generation 3-way catalyst.

7.3.17.3 Progress and Problem Areas

Progress and Problems - 1976 Model Year

Volvo will probably have no problems in meeting the 1976 requirements if they keep their systems the same as may be the case. Some work is underway to try to eliminate the air pump for 1976, and if this is successful, a cost savings is possible.

Progress and Problems - 1977 Model Year

Volvo has made more progress in durability testing of 1977-type systems than any other manufacturer. Volvo has had systems running on high-speed durability and taxi service, in addition to AMA mileage accumulation. The durability experience has been generally favorable with both the '77 oxidation catalyst system and the 3-way systems targeted for 1.5 to 2.0 NOx. The report team concludes that Volvo has demonstrated the capability to run 50,000 miles below the 0.41 HC, 3.4 CO, 2.0 NOx levels consistently.

A problem mentioned by Volvo was the inability to get improved catalysts and substrates from the suppliers. This could be a problem since Volvo wants to use a better catalyst to avoid spark retard. Whether or not spark retard for HC control is going to be necessary or not depends on the success of Volvo's lean choke and cold-start acceleration enrichment development programs both of which look very promising. Volvo has tested other advanced systems such as a partial thermal reactor and electrically heated fuel injectors, but they prefer not to use those approaches.

Progress and Problems - 1978 Model Year

Volvo has progressed during the last year to become the leader in 3-way catalyst technology, the 3-way approach being Volvo's only real system at the 0.41 HC, 3.4 CO, 0.4 NOx level. The experience with the 3-way systems targeted toward 2.0 NOx (no EGR was used) show the capability to achieve 0.41 HC, 3.4 CO, and approximately 1.0 NOx with no EGR. Volvo says that EGR will cut the NOx about 50% but the fuel economy and driveability advantages of the 3-way approach are lost. If the NOx standard were 1.5 or 2.0 NOx Volvo would still go 3-way, because they really like the approach.

The O_2 sensor now has durability satisfactory to Volvo (more than 12,000 miles), and several promising 3-way catalysts have been tested. Volvo's catalyst aging tests showed a new catalyst just labeled "prototype" catalyst that had better efficiencies for HC, CO and NOx than any catalyst Volvo has tested to date but no car data were mentioned. Another progress area for Volvo has been catalyst mechanical durability which they now feel is adequate. Volvo is one of the few manufacturers continuing to make a reasonable effort to meet 0.4 NOx, in the opinion of the report team, and no manufacturer has a better chance with the 3-way approach.

APPENDIX A

DISCUSSION OF THE METHODOLOGY

In the main body of this report the report team makes conclusions about the capability of manufacturers to certify vehicles at various emission standards. This appendix describes the methodology used by the report team to arrive at those conclusions.

The subject of the appropriate methodology to use when estimates are made of the capability of manufacturers to meet future emission standards has been one that has received much attention in the past few years. The major area of discussion has been the methodology that the Administrator of EPA has used in making decisions concerning technological feasibility. This determination is one of the four determinations that he must make under the requirements of the Clean Air Act, when he makes a decision to grant or deny an applicant's application for suspension of the standards.

The EPA methodology used by the Administrator has evolved during the past few years from the methodology used in the first suspension hearings to the one used in the latest suspension hearings. Much of the evolution of the EPA methodology used in the suspension hearings was due to suggestions made by the U.S. District Court of Appeals (District of Columbia Circuit) in their decision in the case International Harvester vs. Ruckelshaus. The latest EPA methodology for analysis of data from applicants in suspension hearings can be found in Appendix B to the decision of the Administrator on remand from the United States Court of Appeals for the District of Columbia Circuit, April 11, 1973. The methodology used in this report is a different methodology than that used by EPA in the above-mentioned analysis of suspension hearings data. There are two main reasons for this.

The first reason has to do with the nature of this report. This report is a report to the Administrator of EPA on the current status of emission control technology and the outlook for future development and demonstration. This report is intended to have two main uses. The first use is as a briefing-type document for the Administrator and other EPA officals as to what the current status of advanced emission control system development is. The second use is as a document in which the important technical issues related to the capability of the manufacturers to meet future standards is discussed, and in which, the EPA technical staff's best judgements on the important issues are transmitted to the Administrator. Thus, the nature of the report is different than the technical appendixes to the Administrator's decisions which have employed the other methodology.

The second reason has to do with the data available. Any methodology for analysis of data is necessarily a function of the type, extent, and quality of the data to be analyzed. Additionally the length of time it takes to apply a methodology to data should be compared to the time available for analysis. Most of the data supplied by manufacturers in their 1974 Status Reports was of a nature that essentially precluded the use of the suspension hearings-type methodology. This is because the suspension hearings-type methodology requires that extensive durability data on a wide variety of vehicles be available. These vehicles should ideally be targeted toward the standards in question. This type of data was not generally available in the manufacturer's Status Reports.

The methodology used in this Report involved use of the following sources of data.

1. The 1974 and 1973 Status Reports submitted by the manufacturers.
2. 1975 Certification Data.
3. The technical literature.
4. The November 1974 NAS report.
5. The results of the methodology previously used in the suspension hearings.

The manufacturer's 1974 Status Reports were used to gauge the current development status of the manufacturers, and by comparison to their 1973 Status Reports help determine the progress that had been made in the year long interval.

The 1975 certification data were used to investigate the current level of technology that the manufacturers have already demonstrated in certification.

The technical literature was examined to keep abreast of the latest published information in the area of emission control and fuel economy.

The November 1974 NAS Report was studied as a source of data and informed opinion in the area of emission control technology and as an indication of technical issues considered important by the NAS.

The results of the suspension hearings-type methodology were used to determine what emission levels at 50,000 miles could be expected to result in a high probability of success in certification. These values were taken as typically between 70 and 80 percent of the standards, depending on the specific pollutant and emission control system.

The report teams estimates of the ability of manufacturers' ability to meet future standards is based on study and analysis of the above data sources. The estimates represent the collective judgement of the report team. Specific assumptions involved in arriving at the conclusions can be found in the body of this report.

APPENDIX B

EMISSION CONTROL, TECHNOLOGY, AND FUEL ECONOMY

During the preparation of this report the report team experimented with several ways to describe the relationships between fuel economy, emission control and level of technology. As discussed in Section 3, the relationship is fundamentally one of three variables, and just examining two of them may be misleading.

The relationships are depicted schematically in the figures that follow in this Appendix. The representations are 3-dimensional surfaces, the variables being emission control, fuel economy, and control technology.

The variables on the figures are qualitative in nature. Increasing emission control is indicated in the direction of the arrow on the "emission control" axis, increasing fuel economy (relative to uncontrolled vehicles) is indicated in the direction of the arrow on the "fuel economy" axis, and increasing emission control system capability is indicated in the direction of the arrow on the "control technology" axis.

Figure B-1 shows the general shape of the 3-dimensional surface. At any given fixed value of one of the three variables, the relationship between the other two can be seen by passing an imaginary plane through the surface.

Figure B-1

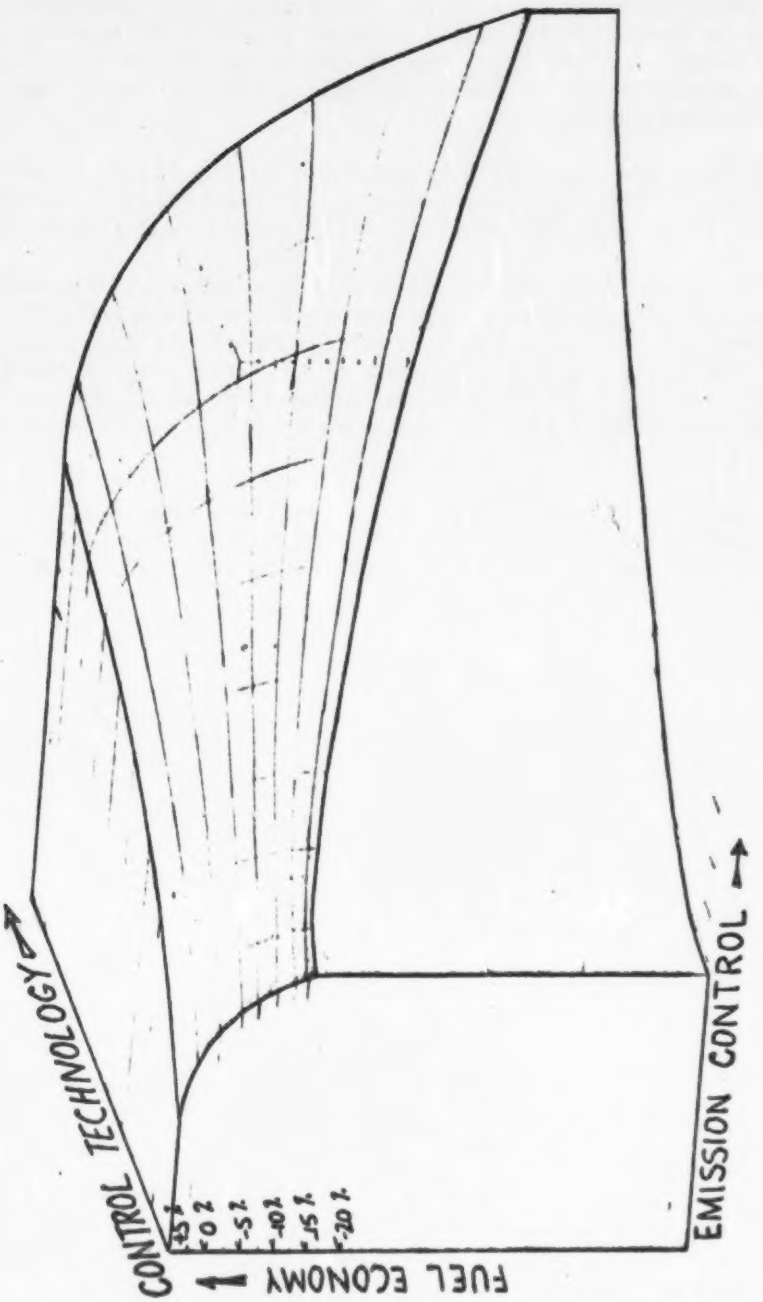

CONTROL TECHNOLOGY
EMISSION CONTROL
FUEL ECONOMY
+5 %
0 %
-5 %
-10 %
-15 %
-20 %

Figure B-2 shows the case for the 1973-4 Federal standards. The intersection of the plane labeled "3,28,3.1" indicates the range of control system/fuel economy combinations that could have been used. The "*" indicates the location of a typical U.S. car. The low level of control system sophistication used (considerable reliance on spark retard) resulted in a fuel penalty of about 15%, compared to uncontrolled vehicles.

Figure B-2

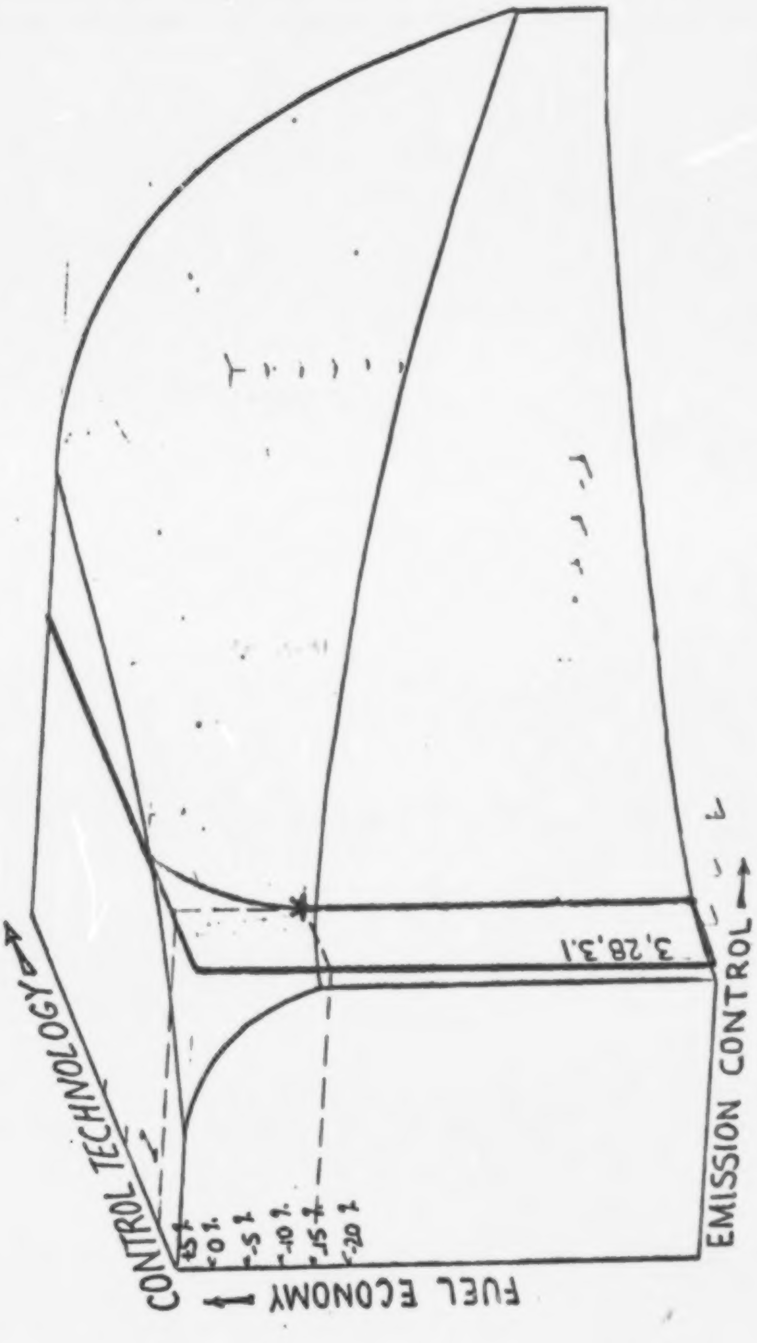

CONTROL TECHNOLOGY
FUEL ECONOMY
EMISSION CONTROL
+5%
0%
-5%
-10%
-15%
-20%
3,28,3.1

Figure B-3 shows the case for the 1975 Federal Interim Standards. Of the range of control system/fuel economy combinations possible, the choice of more advanced control technology (catalysts) resulted in a fuel economy benefit compared to 1974, despite the 50% reduction in HC and CO emissions required by the standards.

Considering the star on figure B-3, the fuel economy gain over 1974 is seen to be a result of moving toward increased control technology, which permitted optimization for fuel economy. Had 1974-type systems been used, the resultant fuel economy would have been lower, at the same level of control technology as was shown by the star on figure B-2.

Figure B-3

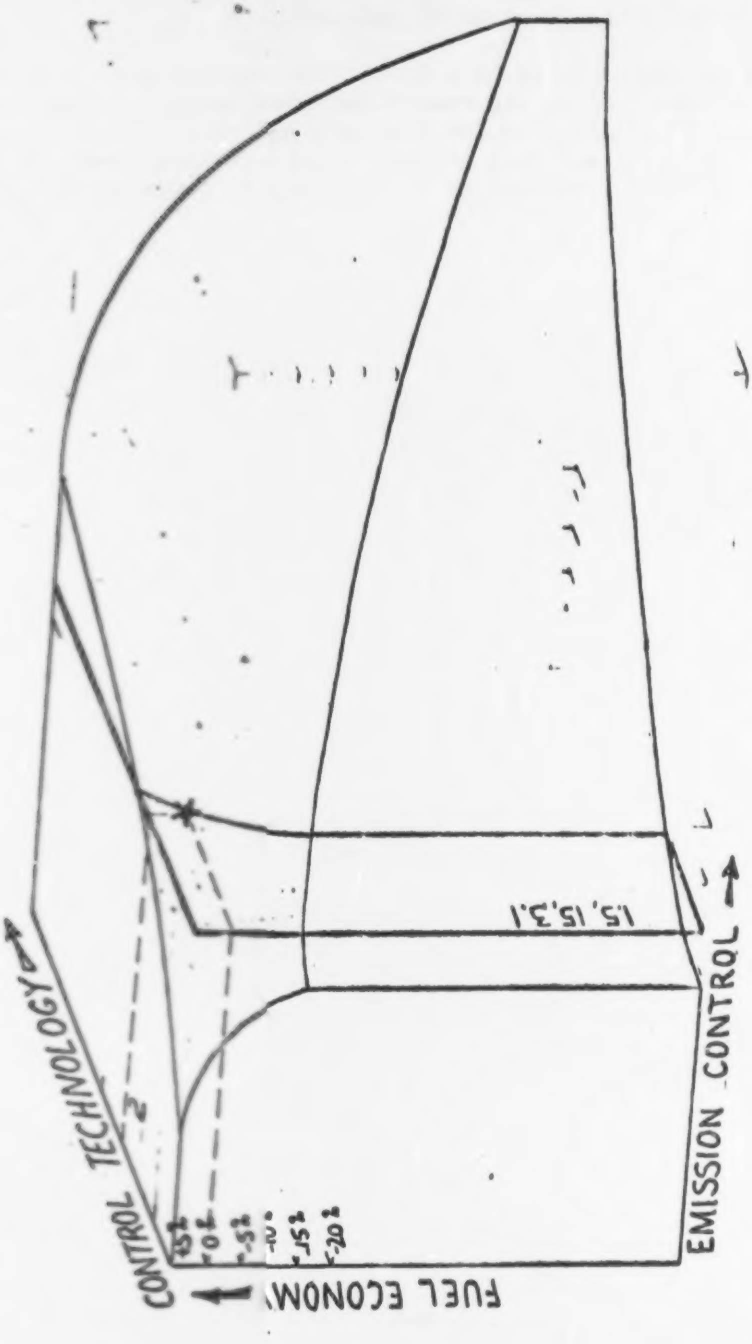

CONTROL TECHNOLOGY
FUEL ECONOMY
EMISSION CONTROL
1.5, 15, 3.1
2
+5%
0%
-5%
-10%
-15%
-20%

Figure B-4 shows that at the 1975 "California" level the control technology used was not sufficiently advanced to prevent a loss in economy compared to the Federal interim standard cars. However, exceptions exist. Saab, for example, did not drop lower on the surface due to the use of sufficiently advanced technology.

Figure B-4

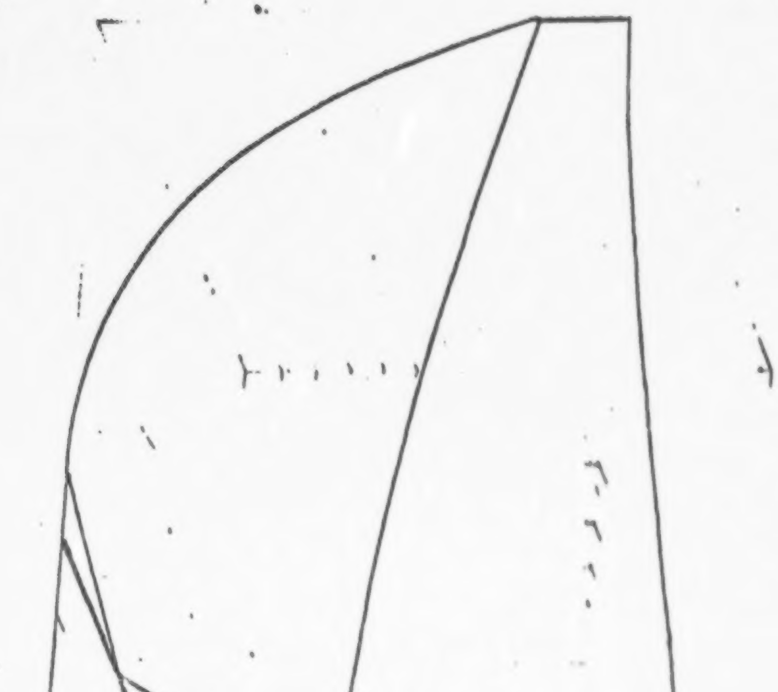

CONTROL TECHNOLOGY
3
FUEL ECONOMY
EMISSION CONTROL
+5%
0%
-5%
-10%
-15%
-20%
.9,.9,2.0

Figure B-5 shows the surface for the statutory 1977 standards. Current industry claims are that a fuel penaly will be realized in meeting this goal. As shown in the figure, this would be expected if the control technology used is the same as that used for the California standards. Whether or not a fuel penalty will be avoided or a gain will be achieved depends on the emission control techniques selected. The level of control technology necessary to achieve the .41, 3.4, 2.0 level with fuel economy as good or better than 1975 model cars may be possible with several different control approaches.

The range of fuel economy values possible lies between the two stars on figure B-5

Figure B-5

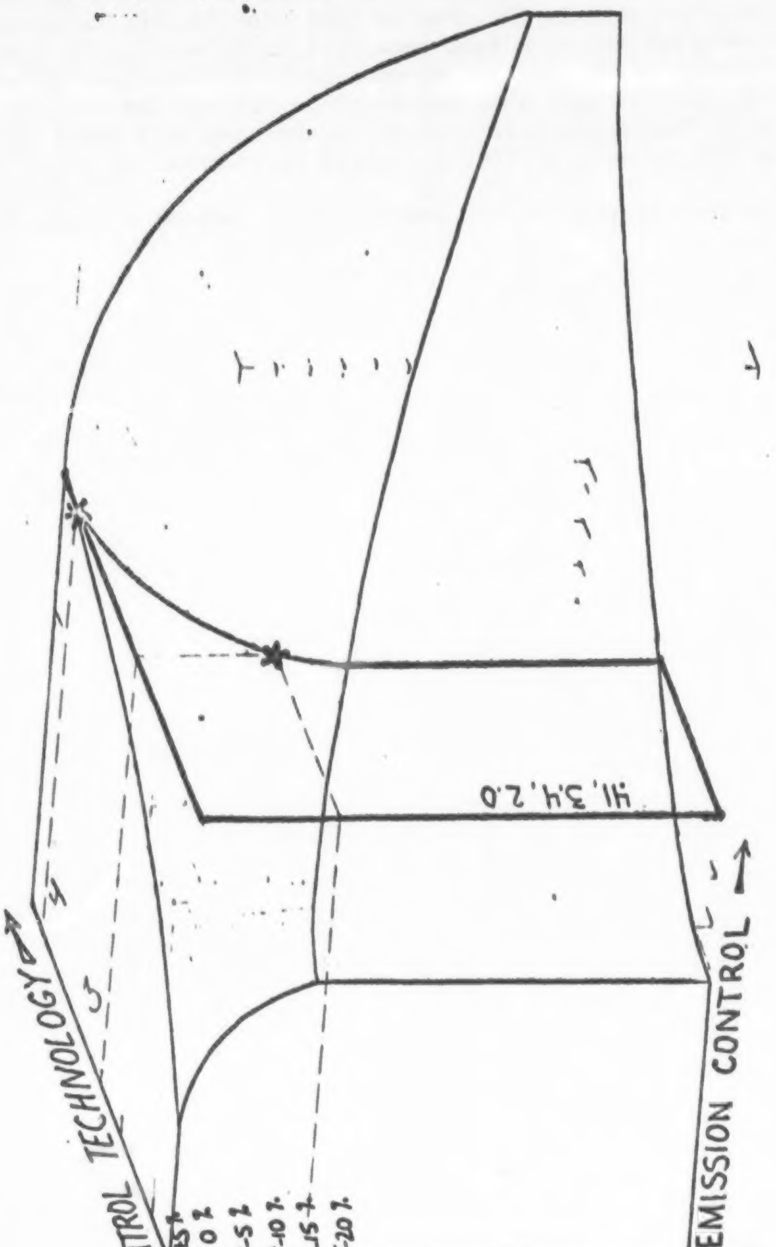

CONTROL TECHNOLOGY
EMISSION CONTROL
FUEL ECONOMY
+5%
0%
-5%
-10%
-15%
-20%
.41, 3.4, 2.0
3
4

Figure B-6 summarizes the previous figures. Looking at figure B-6 one can see the following trends:

- From 1974 to 1975 Federal we moved from a level of low technology (engine calibration changes, engine mods) and low fuel economy to more advanced technology (catalysts) and improved fuel economy.
- The 1975 California standards resulted in a slight fuel economy loss and the use of slightly more advanced technology.
- The fuel economy associated with the 1977 standards will depend on the system used to achieve compliance. No system change from 1975 California will cause a fuel economy loss.

The 1977 systems could be anywhere on the line connecting the two stars labeled 77 with a question mark.

Figure B-6

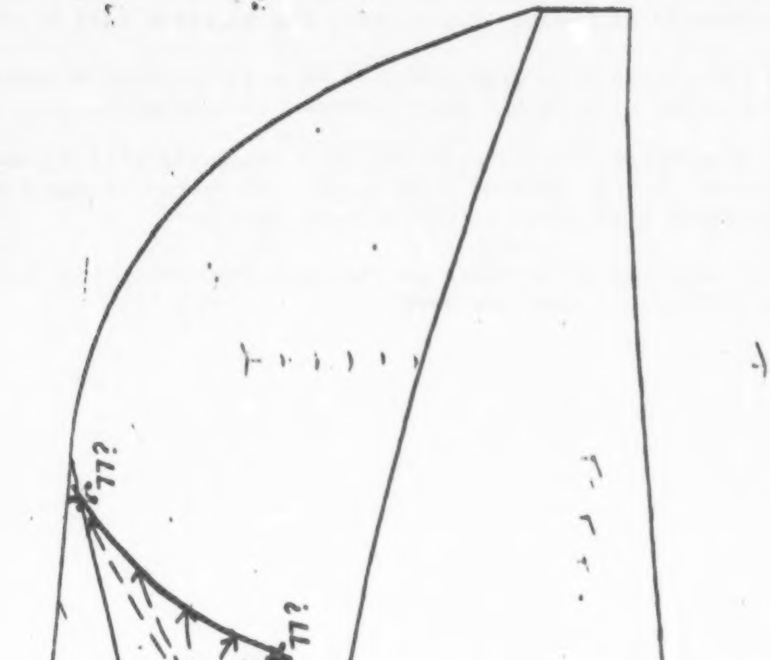
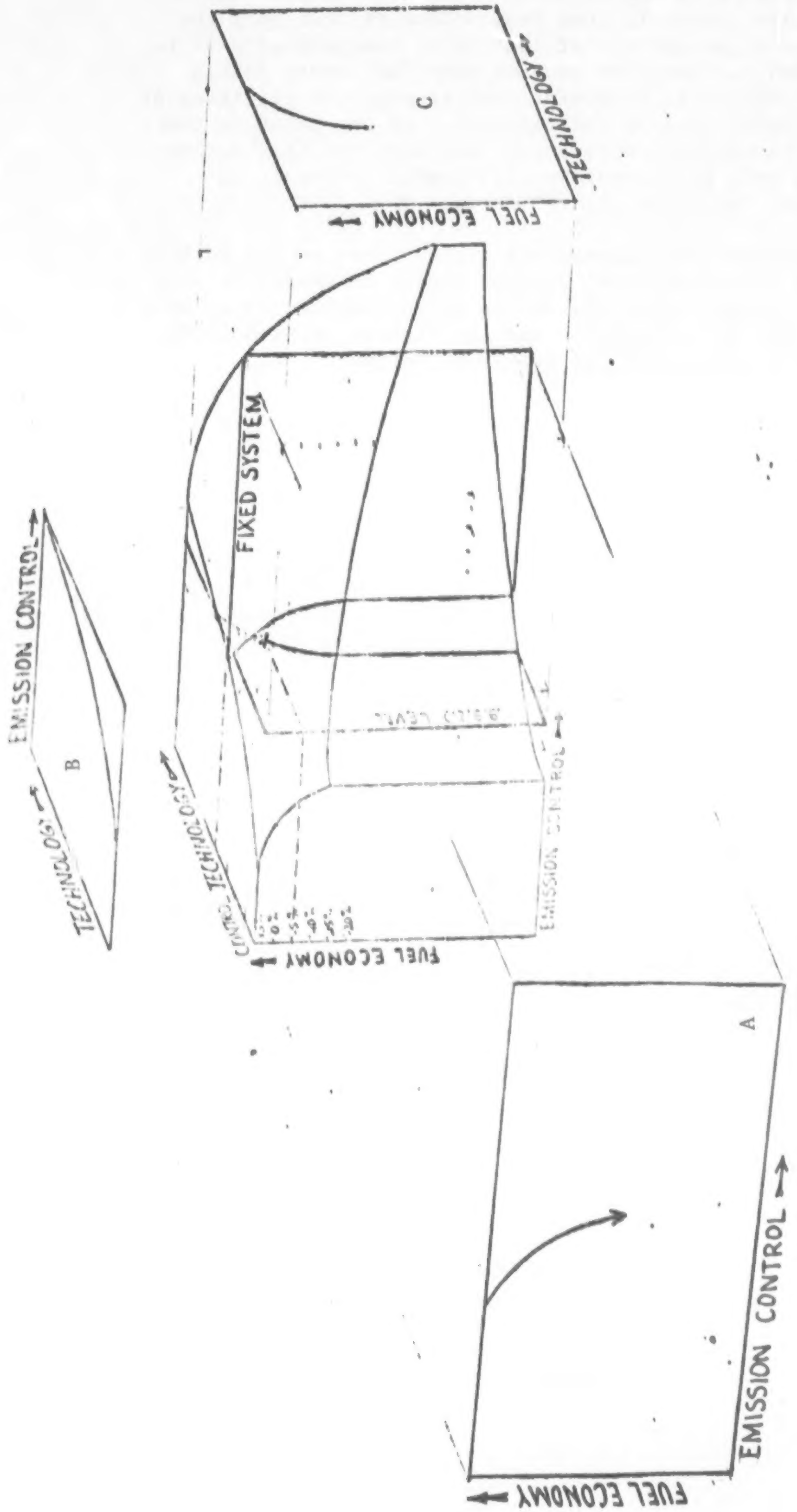

CONTROL TECHNOLOGY
FUEL ECONOMY
EMISSION CONTROL
+5 %
0 %
-5 %
-10 %
-15 %
-20 %
74
75 FED
75 CAL
77?
77?

Figure B-7 shows where the three different "two dimentional" ways of looking at emission tradeoffs come from. None of them tell the whole story. The most popular way of looking at the tradeoffs is to consider fuel economy vs. emission control with "all other things equal". This is a simplistic viewpoint that ignores the realities of available and developing control technologies. At any point in time the use of control technology necessary to minimize the fuel economy impact of stringent emission standards will generally result in increased system complexity and costs.

There are three different two-dimensional graphs shown on figure B-7. The one (labeled A) that shows fuel economy versus emissions is only valid for a fixed system. Likewise the top graph (labeled B) is only valid for a given fuel economy level, and the figure (labeled C) is only appropriate at a given level of emission control.

Figure B-7


FUEL ECONOMY
EMISSION CONTROL
A
FUEL ECONOMY
CONTROL TECHNOLOGY
EMISSION CONTROL
FIXED SYSTEM
LEVEL
TECHNOLOGY
EMISSION CONTROL
B
FUEL ECONOMY
TECHNOLOGY
C

THE TRADE-OFFS ASSOCIATED WITH LOW EMISSIONS DEPEND ON ONE'S POINT OF VIEW

It is important that the different ways to look at fuel economy, emission control, and technology be understood. This enables one to resolve different points of view on the complicated subject of fuel economy and emissions, and also to keep from being misled.

APPENDIX C

UNREGULATED EMISSIONS

C.1 Introduction

Very little information on unregulated emissions was included in the recent submissions to EPA; GM, Ford, Chrysler, and several foreign manufacturers included some limited information on sulfates supplemented by some SAE and other publications on the subject. The manufacturers submitted more extensive information on sulfates to EPA earlier in the year in response to a March 8, 1974 Federal Register request for such information. The companies have reported very little new information since then.

This Appendix will summarize the information submitted with regard to the work done to date on sulfates and discuss the current outlook for control of sulfate emissions from catalyst vehicles. Almost no information was submitted on other unregulated emissions such as POMs, reactive organics, aldehydes, catalyst attrition products, noble metal emissions such as platinum and palladium, other sulfur compounds such as hydrogen sulfide, and other miscellaneous compounds such as phosphine. Therefore, these other emissions will not be discussed in this appendix although they were mentioned in Section 5.

C.2 Measurement Methods for Automotive Sulfates

The two basic measurement procedures used for automotive sulfates are the condensation method and the absorption method. The absorption method was used by Chrysler and EPA in some early work. The condensation method is used by all other investigators including EPA and is the preferred method to measure sulfates.

The condensation method involves diluting the entire vehicle exhaust with great quantities of dilution air which cools the exhaust and allows formation and condensation of sulfate particles. The sulfate is collected by filtering a small stream of the diluted exhaust through a nuclepore, millipore, glass fiber or other filter. The filter can then be analyzed for sulfates by a number of standard methods.

The absorption method involves passing a small quantity of undiluted exhaust through an impinger containing isopropyl alcohol. The sulfate is absorbed in the isopropyl alcohol and can be analyzed directly. Unfortunately, small quantities of sulfur dioxide can also be absorbed in the isopropyl alcohol and are later converted to sulfate. This method can give spuriously high sulfate readings and is not considered by most investigators to be accurate.

C.3 Sulfate Emissions From Non-Catalyst Cars

Until recently, the magnitude and form of sulfur oxide emissions from automobiles has been of relatively little interest compared with other automotive emissions. However, after testing revealed high sulfate emissions from catalyst-equipped cars, it became important to know how much of this was a result of the catalyst, and now much sulfate had been in the auto emissions all along.

Reporting on tests performed on non-catalyst cars, all investigators except one have confirmed the belief that no appreciable amount of fuel sulfur is converted to sulfate in a non-catalyst car. Chrysler, using the absorption measurement technique EPA has since found unreliable for auto exhaust, found almost as much sulfate in non-catalyst exhaust as in catalyst exhaust.

Other tests using the condensation method show only trace quantities of sulfates from non-catalyst cars. Extensive tests have been run by GM, Ford, Exxon, Ethyl, and EPA under various driving conditions for 1974 type cars. These tests show an approximate emission factor of about 1 milligram per mile or less than 1% conversion of fuel sulfur to sulfate.

C.4 Sulfate Emissions from Catalyst-Equipped Cars

When preliminary tests revealed that catalyst-equipped cars emit a significant amount of sulfate in their exhaust, more extensive testing was done. Results from this testing have so far indicated that there are a wide variety of possible influences on sulfate emissions.

Some of the largest differences in emissions have been attributed to the type of catalyst used. In most types of driving, pelleted catalysts show very different behavior than monolith catalysts. A major factor in causing this difference between pelleted and monolith catalysts appears to be the existence of a "storage effect" whereby catalysts at certain operating conditions (most notably cold-start and low-speed driving) appear to be storing a portion of the sulfur compounds in the engine exhaust. Many of the tests have shown that pelleted catalysts exhibit a substantially larger storage effect than monolith catalysts, which store very little, if any, sulfur compounds when used with non air injection equipped vehicles. When sulfur compounds are being stored by the catalyst, low sulfate emission rates result. During other types of driving, previously stored sulfur compounds may be released.

Because of this storage effect, the generation of repeatable and meaningful sulfate emission data, particularly for cars with the pelleted catalyst, becomes quite complicated. One approach might be to make measurements only after stabilized conditions (determined by no net gain or loss of sulfur compounds from the catalyst over the test) have been reached. Unfortunately, the type and extent of preconditioning required to reach such stabilized conditions are not yet known. However, it is not clear that results obtained after such preconditioning would be truly representative of emissions from vehicles in actual use, since a substantial part of the emissions in reality might be from non-stabilized vehicles.

C.4.1 The Storage Effect

In many of the tests performed on catalyst equipped cars, the total sulfur emitted as SO_2 plus SO_3 in the exhaust was substantially less than either the amount of sulfur in the fuel consumed by the engine or the total sulfur measured in the exhaust before the catalyst. Since in tests with non-catalyst cars the sulfur recovery was usually over 90%, this is considered evidence of sulfur "storage" on the catalyst. This storage phenomenon has been detected at times under many types of driving conditions, and appears to be related to both the previous history of the catalyst and its immediate operating conditions.

Storage of sulfur compounds on a catalyst is probably caused by a chemical reaction of these compounds with the alumina support. To date, it is believed that sulfate may be the primary compound stored on catalysts even though SO_2 is theoretically capable of being stored as sulfite. This is based on work done by Ford. Some recovery of stored sulfur as SO_2 suggests that the latter phenomenon is also occuring.

Large quantities of sulfate can be stored on the pelleted catalysts due to the large mass (up to 8 lbs.) and surface area of alumina present. The monolith catalysts consist of a low mass cordierite support covered with an alumina washcoat. While the washcoat itself may adsorb sulfur compounds, one would expect the amount adsorbed by the low mass washcoat to be considerably less than that adsorbed by the much higher mass of alumina in a pelleted catalyst.

Storage for Pelleted vs Monolith Catalysts

During cold-start FTP tests conducted by GM, both pelleted and monolith catalysts stored sulfur. Storage for precious metal pelleted catalysts with air injection (AIR) ranged from 25-90% of the fuel sulfur. Noble metal monolith catalysts with AIR demonstrated comparable storage of 40% to 80%, but only 10% without AIR.

In tests under 60 mph cruise conditions, Ford used fresh catalysts with little or no preconditioning. They discovered practically no storage for monolith catalysts when the data were averaged over a 2000 mile run. However, the results of the individual tests conducted at intervals during the 2000 miles would sometimes show storage of up to 15-20%, and at other times, net releases of sulfur. Since the total set of results averaged to very nearly zero sulfur storage, the individual variations were taken to be a result of the measurement techniques. In a similar test with a pelleted catalyst, 24% storage was exhibited both at the beginning and end of a 1000 mile run, but the supporting data are weak.

For GM's 60 mph tests, catalysts were used which had previously been subjected to 20 or more consecutive FTP's. In an initial 10 minute test, sulfur recovery was always greater than 100%, going as high as 422%, indicating release of stored sulfur. The results for extended 60 mph cruise conditions were less consistent. The pelleted catalyst without AIR showed large initial release, stabilizing to about 100% recovery. The pelleted catalyst with AIR exhibited both release and storage, with no stabilization after 4 hours. A monolith catalyst with AIR showed a short initial release, developing to a fairly stable pattern of about 20% storage at the end of 4 hours. Therefore, sulfate storage is greatest for a pelleted catalyst type under FTP conditions.

Time Required for Storage

In efforts to find out something about the storage capacities of different catalysts operating under different conditions, several tests observed the time or mileage required to reach a steady output of sulfur. If the initial transient emissions caused by storage has stopped and the sulfur in the exhaust equals the fuel sulfur intake, then the catalyst must be in equilibrium. If the catalyst shows a steady storage or release of sulfur, then stabilization has been reached, but not equilibrium.

Overall, the submissions indicate that a stable rate of sulfur storage (stabilization) was achieved after about 1000 miles of operation under steady-state high speed operating conditions for both pelleted and monolith catalysts which had a history of only little low speed driving. However, only the monolith catalyst appeared to achieve equilibrium (no further storage) within that period. Tests with catalysts with histories of multiple FTPs failed to provide conclusive evidence of either stabilization or equilibrium after a thousand miles or so of operation under steady conditions.

This storage problem means that it will be very difficult to obtain accurate emission factors for pelleted catalysts under the FTP. Emission factors must be estimated based on engineering judgement.

C.4.2 Comparison of Pelleted and Monolith Sulfate Emission Factors

Much of the test data that has been given to EPA was the result of attempts to determine differences in sulfate emissions between monolith and pelleted catalysts. Such a difference might result in a lower lifetime sulfate output, or lower sulfate emissions under conditions which have a high potential of air quality impact, such as urban "canyon" driving conditions.

The data indicate a high variability in absolute sulfate emission magnitudes among different driving conditions. Some of these variations are manifestations of the storage effect, while others suggest relationships between sulfate emissions and catalyst operating parameters.

Sulfur Emission Rates Without Storage Effects

Sulfate emissions under FTP driving tests are usually substantially higher for monolith catalysts than for pelleted catalysts, as detailed in the next sub-section. However, these are usually at neither stabilization nor equilibrium states. Such results reflect the greater storage capacity of pelleted catalysts.

In tests which did reach stable sulfate emission rates, Exxon Research and Engineering specially preconditioned both pelleted and monolith catalysts at a certain fuel sulfur level, then ran them at 60 mph cruise conditions at a different fuel sulfur level. For both catalyst types, the initial transients caused by storage stopped after about 60 minutes, and the sulfate emission rates stabilized at nearly identical levels.

Tests involving extended mileage accumulation on pelleted and monolith catalysts were conducted by Chrysler. They ran a monolith catalyst over 50,000 miles, and a pelleted catalyst for 20,000 miles. The monolith catalyst initially released 8.4% of the fuel sulfur as sulfate, but after 2,000 miles maintained a steady rate of 10.4%. The pelleted catalyst showed much larger initial variations during the first 1,000 miles, but recorded a 10.3% conversion at 20,000 miles, equivalent to the monolith. No firm conclusions should be drawn from this because Chrysler did not include in its submissions information regarding what kind of driving conditions the catalysts were subjected to. However, these tests indicate that monolith and pelleted catalysts may have similar sulfate emissions after a short initial mileage period.

Thus, the limited data available indicate that when sulfur storage on the catalyst is not a factor, pelleted and monolith catalysts convert fuel sulfur to sulfate at comparable rates.

Sulfate Emissions Under Typical Driving Conditions

The relative sulfate emissions for pelleted and monolith catalysts under typical driving conditions are of considerable interest. The particular driving conditions examined are: extended urban-type driving, extended highway type cruises, and the period of initial transition from urban driving to highway driving.

For a cold-start FTP, which is indicative of urban driving, GM found sulfate emissions from monolith catalysts to be about three times as great as the pelleted catalyst emissions. Similarly, Exxon Research and Engineering found greater sulfate emissions over the FTP for the monolith versus the pelleted catalyst.

In the consecutive FTP tests conducted by GM (approximating extended urban driving), average sulfate emissions from catalysts indicate that the monoliths emit about seven times as much sulfate as pelleted catalysts. However, the actual emissions from the consecutive FTPs were highly inconsistent.

Under 60 mph cruise stabilized conditions (extended highway driving), Exxon Research and Engineering found almost identical emissions from pelleted and monolith catalysts, with the monoliths having a slightly higher percent conversion. In a Ford study, where fresh catalysts were used, both exhibited the same percent conversion, but the pelleted catalyst emitted less because it was still storing sulfates. In GM tests involving extended 60 mph driving following a series of consecutive FTPs, the pelleted catalysts averaged 22-35% conversion of fuel sulfur into sulfate. The monolith catalyst averaged 31% over a four-hour test by GM.

GM ran the same catalysts for ten minutes at 60 mph immediately following the series of consecutive FTP tests, approximating the transition from extended urban driving to normal highway-speed driving. For one pelleted catalyst, the FTP sulfate level was increased by over 25 times during this transition period, while the SO_2 level jumped to 7 times its former level. During this test, over 4 1/2 times as much sulfur was being emitted as exhaust than was consumed as fuel sulfur. Again, the results were not consistent with some of the catalysts tested showing much lower sulfur release.

Some of the respondents determined that the amount of excess sulfur released during the urban-to-highway transition was comparable to the quantity of sulfur stored during the low-speed, urban driving period. Testing by EPA indicates that most of the sulfate stored at low speeds is recovered during the transition period, although there is a lower percent conversion to sulfate of recovered sulfur compounds. If these results are confirmed, it would then appear that pelleted catalysts have somewhat lower lifetime sulfate emissions than do monoliths.

Some typical emission factors are given in Table C-1 for different catalysts over different driving conditions. These average emission factors were taken from the submissions to EPA and were based on 0.03% sulfur fuel (300 ppm sulfur) or a linear extrapolation to 0.03% sulfur fuel. The numbers based on multiple tests are considered more reliable than the single test data points. Air injection was used in all cases except where noted.

Table C-1

Average Sulfate Emissions

Driving Condition	Test Group	Catalyst	Number of Tests	Average Emission*
60 mph cruise	Ford	Monolith	8	57
		Pelleted	2	50
	Exxon R&E	Monolith	4	53**
		Pelleted	22	60
	GM	Monolith	2-8	48
		Pelleted	4-16	48
		Pelleted, No AIR	6-24	44
40 mph cruise	Exxon R&E	Monolith	18	47
		Pelleted	4	16
	Ethyl	Monolith	6	63
	GM	Monolith	2-8	76
30 mph cruise	Ford	Pelleted	2	74
	GM	Monolith	2-8	62
		Pelleted, no AIR	2-8	9
1972 FTP	Exxon R&E	Monolith	18	66**
	GM	Monolith	16-64	26
		Pelleted	46-184	10
		Monolith, no AIR	4-16	1
		Pelleted, no AIR	12-48	2

*In milligrams of H_2SO_4 per mile, with 0.03% sulfur fuel (mg/mi/300 ppm)

**Results obtained by Exxon in later work under an EPA contract are considerably lower than these emissions. These results are about 30 milligrams/mile.

Table C-1 (cont.)

Average Sulfate Emissions

Driving Conditions	Test Group	Catalyst	Number of Tests	Average Emissions*
1975 FTP	Exxon R&E	Pelleted	13	16
Ten Minutes at 60 mph after extended FTP running	GM	Pelleted	6-24	83
		Pelleted, no AIR	2-8	13
10 mph cruise	GM	Pelleted, no AIR	2-8	0**

---

* In milligrams of H_2SO_4 per mile, with 0.03% sulfur fuel (mg/mi/300 ppm).

**Presumably, GM means that the amount of sulfate present was below their limit of detection.

C.4.3 Best Estimate Sulfate Emission Factors

It has been demonstrated that the level of sulfate emissions depends on the catalyst type, the driving conditions, and sulfur storage from previous conditioning. To develop a set of emission factors for use in air quality impact modeling, all of these considerations must be taken into account.

For example, there must be separate emission factors for 60 mph cruise conditions and initial 60 mph driving after extended low-speed or FTP driving, because of the large storage effect to be expected in the latter case. Also, separate emission factors are needed for monolith and pelleted catalysts. To develop an overall average emission factor for any particular driving condition, the proportion of monolith catalysts to pelleted catalysts must be estimated.

For the following best estimate emission factors, all of the sulfate emissions were normalized to a fuel sulfur level of 0.03% (300 ppm S) which is the current national average. Implicit in this procedure is the assumption that the sulfate emissions are linearly dependent on the fuel sulfur level.

From all of the data, best estimate emission factors for several driving conditions have been compiled and are presented in Table 2. Results of the FTP, 30 mph, and 40 mph tests are grouped together for the urban conditions category, low-to-moderate speeds. The 60 mph tests comprise the highway conditions category, and the GM short 60 mph tests after extended FTP conditioning and similar EPA tests make up the urban-to-highway cruise transition category.

For both pelleted and monolith catalysts, the emission factors assume the use of air pumps. These emission factors are based on the fuel economy achieved by 1975 cars in the 5000 lb. inertia weight class (i.e. the full size car). Any improvements in fuel economy in future years would result in lower sulfate emissions since the amount of sulfate formed is directly proportional to the total amount of gasoline burned. These emission factors are also based on 0.03% sulfur level fuel, the current national average. These emission factors would be higher for areas such as Southern California with higher sulfur level fuels (0.05% average).

Table C-2

Best Estimate Sulfate Emission Factors*

	Pelleted Catalyst	Monolith Catalyst
Urban driving	10 - 15	30
Highway cruise	50 - 60	50 - 60
Urban-to-highway cruise transition	100 - 300	50 - 60

* mg/mi assuming 300 ppm S fuel

C.5. Sulfate Emissions from Advanced Emission Control Vehicles

No information was supplied on sulfate emissions from vehicles with dual catalyst or three-way catalyst systems. Both of these systems are used for NOx control as well as HC and CO control. These types of control systems are not planned for production for the model year 75-77 years but would be required to meet model year 78 standards.

Very little data has been submitted to date on the subject of sulfate emissions from alternative engines. The only records of alternative engine tests were supplied by GM, which tested a Diesel, a rotary, and a stratified charge engine.

The Diesel was a 1973 Opel with no special air pollution control equipment. It showed sulfate emissions to be about the same on a mg/mi/ppm S basis as a non-catalyst car, but this translates into relatively significant sulfate emission rate when the high sulfur content of Diesel fuel is taken into account. Using No. 1 distillate fuel containing 840 ppm fuel sulfur the sulfate emissions were 6 mg/mi, less than catalyst cars at FTP conditions. The sulfate emission for No. 2 distillate (3900 ppm fuel sulfur) was 16 mg/mi.

Tests of the following four alternate engines showed sulfate emissions similar to non-catalyst cars:

Honda CVCC
GM Experimental Stratified Charge
GM Rotary without catalysts
Toyo Kogyo Rotary with thermal reactors

C.6. Control Through Vehicle Modifications

C.6.1 Engine/Catalyst Modifications

Only very limited information was included in the submission on how vehicle or catalyst parameters affect sulfate emissions and how these parameters can be altered to reduce sulfate emissions. Ideally, some parameters such as catalyst formulation, catalyst temperature, air injection rates or space velocity could be changed to reduce sulfates to an acceptable level and yet maintain adequate control of HC and CO emissions. However, most companies are only beginning programs in this area and have no results to report.

Catalyst Formulation

Regarding catalyst formulation, GM reports some data showing base metal catalysts to have low sulfate emissions while noble metal catalysts have significantly higher sulfate emissions. While use of base metal catalysts for control of HC and CO emissions was rejected by auto manufacturers due to poor durability, this poor durability was due in part to sulfur poisoning (possibly storage) at lower temperatures. If fuel sulfur levels were reduced to where the base metal catalysts are no longer subject to poisoning the base metal catalyst would have the advantage of substantially lower materials cost. This assumes that there are not other durability problems.

No work was reported on how various noble metal formulations affect sulfate emissions. Possibly a Pt-Pd mixture gives different sulfate emissions than Pt alone. This point is being examined by an EPA contract with Exxon.

Catalyst Structure

GM states that the basic catalyst structure of monolith versus pelleted is an important parameter in controlling sulfate emissions. According to GM, a pelleted catalyst, due to its greater capacity to store sulfates, would have lower sulfate emissions over the FTP when fresh than a monolith catalyst. After the sulfate storage on the pelleted catalyst has stabilized to some degree, sulfate emissions increase. However, all tests have shown the pelleted catalyst to still have lower sulfate emissions than the monolith over the FTP.

However, both catalysts have equivalent stabilized sulfate emissions at 60 mph. Before determining that a pelleted catalyst has lower overall sulfate emissions than a monolith catalyst, the fate of the stored sulfur compounds must be determined. If all of these stored compounds are later released as SO_3, the pelleted catalyst may have overall sulfate emissions identical to those of a monolith catalyst. These points are discussed in more detail in a prior section. It is our judgment at this time that substantial sulfates are released from a pelleted catalyst in the transition from low to high speed driving.

Catalyst Loading

The effect of noble metal loading on sulfate emissions was investigated by GM using a laboratory apparatus and actual engine exhaust. SO_2 and SO_3 emissions were measured from catalysts with 0.1% and 1.0% platinum at a constant temperature. The results are given in Table 3.

Table 3

Effect of Noble Metal Loading on Sulfate Formation

	SO_3, ppm	
Catalyst	1000°F	1100°F
0.1% Pt	7.0	5.7
1.0% Pt	8.2	6.1

These tests show that increased platinum loading results in slightly higher sulfate formation. However, the effect is a small one, indicating that higher noble metal loading required for improved durability at lower emission levels will probably not result in greatly increased sulfate levels.

Catalyst Temperature

Theoretically, catalyst operating temperature is expected to have a significant effect on sulfate formation. The thermodynamic equilibrium constant for SO_2 oxidation is such that higher temperatures lead to decreased sulfate formation. Also, the temperature and activation energy required determine the kinetics for the reaction, i.e., the rate at which the reaction occurs. With the sulfur system, the above parameters are such that at lower temperatures the SO_2 oxidation reaction would be very slow and at higher temperatures SO_2 would not oxidize at all. Unfortunately, automotive catalysts operate most of the time in the intermediate temperature range where SO_2 oxidizes readily. Low temperature operation is not feasible because HC and CO oxidation would also be very slow. High temperature operation results in poor durability.

GM did several experiments measuring SO_2 oxidation rates on pelleted catalysts at various temperatures. The results, which give sulfur emissions as a function of temperature, are difficult to interpret because GM does not indicate previous operating conditions for the catalyst and whether the catalyst has reached equilibrium regarding sulfate storage at the time of the test. These tests indicated that maximum sulfate emissions occur at 1200°F, and that beyond this temperature sulfate emissions decrease. These results do suggest that modification of catalyst operating temperature should be studied for its potential in controlling sulfate emissions.

One item of interest noted in these tests was that emissions of SO_2 and sulfates combined were less than the sulfur input to the catalyst at lower temperatures but increased with increasing temperatures. This is due to storage of sulfur componuds on the pelleted catalyst at low temperatures and the release of the stored compunds at higher temperatures. As the temperature increases, the percentage of total sulfur compounds represented as sulfates decreases. Exxon is also investigating this point in their EPA contract and will have results shortly.

Air Injection Rate

Air injection rate is expected to affect sulfate formation in that excess oxygen results in higher sulfate formation, with all other conditions (e.g., catalyst temperature) being identical.

Initial work was done in this area by GM, who measured sulfate emissions of catalyst cars with and without air pumps. As shown in Table 4, substantial increases in sulfate emissions were found for both pelleted and monolith catalysts when air injection was used.

Table C-4

Effect of Air Injection on Sulfate Emissions
During 1972 FTP

Catalyst	Air Pump	Fuel Sulfur	Sulfates
Monolith (car C-32419)	Off	0.03%	less than 0.001 gm/mi
	On	0.03%	0.02
	Off	0.065%	0.003
	On	0.065%	0.143
Pelleted (car ES83189)	Off	0.026%	0.001
	On	0.019%	0.004

The preliminary tests indicate that, in some cases, the presence of air injection causes a very large increase in sulfate formation. It must also be noted that the results of GM's tests showed large variations from test to test and from vehicle to vehicle. These limited data also showed lack of air injection to result in an approximate twofold increase in HC and CO emissions. Clearly, much more work is needed in this promising area.

GM did additional tests measuring the effect of two levels of oxygen on sulfate formation at five different temperatures. These results, given in Table C-5, show that a twofold increase in oxygen level approximately doubles the amount of sulfate found, at least at lower temperatures.

Table C-5

Effect of Oxygen Level on Sulfate Formation

		SO_3 ppm				
Catalyst	%O2	900°F	1000°F	1100°F	1200°F	1300°F
0.1% Pt (A/F 15.4, SV 28,000)	1%	5.0	4.5	-	7.2	6.5
0.1% Pt	2%	12.7	10.7	11.8	-	-

While these results show the effect of oxygen level on sulfate emissions, they indicate on clear trend of catalyst temperature versus sulfates. Earlier findings showed maximum sulfate formation at 1200°F. It is not possible to resolve this discrepancy at this time. However, these reuslts are promising in that they indicate a reduction of sulfates at lower oxygen levels. Close control of air injection could effectively inhibit much of the sulfate formation.

Some recent work at Exxon under an EPA contract also shows low air injection rates result in low sulfate formation but higher CO emissions.

Space Velocity

Space velocity, in effect, determines the total time period in which the exhaust gas is in contact with the catalyst. Space velocity is the exhaust flow (ft^3/hr) measured at standard temperature and pressure, divided by the catalyst volume (ft^3). The reciprocal of space velocity is contact time usually expressed in hours, that the exhaust gas is exposed to the catalyst. Thus, a smaller catalyst bed results in a larger space velocity number but shorter contact time. A larger catalyst bed generally results in longer contact times and thus more effective HC and CO oxidation, and is less likely to suffer "break through", i.e., exhaust gas passing through the catalyst bed without reacting. However, a catalyst bed that is too large (i.e., a low space velocity number) will have a very long warm-up period and high cold-start emissions. A trade-off is made between these two factors to define an optimum space velocity.

Sulfate emissions can also be affected by space velocity, with a low space velocity resulting in higher sulfate emissions. It should be possible to add sulfates as another variable in defining optimum space velocity.

GM is the only company which reported tests to determine the effect of space velocity on sulfate formation. These tests are summarized in Table C-6 and were run at 1200°F with a pelleted catalyst.

Table C-6

Effect of Space Velocity on Sulfate Formation

Space Velocity	Sulfate Formation
7,000 hr - 1	18%
28,000 hr - 1	14%

These tests results show greater sulfate emissions at lower space velocity, which allows more time for sulfates to form in the catalyst. This result suggests that, at least at 1200°F, sulfate formation is limited by reaction kinetics (i.e., the reaction rates) rather than thermodynamics. Even though the effect of space velocity is small, it seems to be, nevertheless, one more variable to consider in designing a catalyst for low sulfate emissions.

C.6.2 Sulfate Traps

If it is not possible to adequately control the formation of sulfates in the catalysts, it may be possible to control sulfate emissions by use of a sulfate trap after the catalyst. A sulfate trap is a device which by chemical reaction or mechanical means removes sulfuric acid particles and SO_3 from the exhaust gas downstream from the catalyst.

Most of the feasible sulfate traps are chemical traps and involve the reaction of acidic sulfate with a base. Sulfate trap devices,such as limestone scrubbers, were developed to control sulfur dioxide emissions from stationary sources. These traps have not been previously considered for automotive use. Very few comments were received on sulfate traps other than general comments from Ford and GM and some specific comments from Atomics International.

Mechanical Traps

Mechanical traps of a centrifugal separator design have been developed by DuPont, Ethyl, and PPG to remove lead particulates from automotive exhaust. It is theoretically possible that sulfuric acid could be removed by this type of trap if the sulfate particles were condensed into particulates before the exhaust reaches the trap.

The Ford comments on mechanical traps stated that exhaust system temperatures are too high to allow condensation of exhaust sulfates. EPA measurements of temperatures along standard exhaust lines show this statement to be true. Ford mentions that a heat exchanger could be used to lower the temperature of the exhaust. However, this heat exchanger would condense the water in the exhaust if a large temperature drop occurred. If water did condense, and there is a large amount of water in automotive exhaust, the water would not only present a large storage problem, but much of the sulfuric acid could be lost by entrainment. Ford feels it is virtually impossible to maintain the temperature below the condensation point for sulfuric acid yet above the condensation point of water over the wide range of driving conditions.

EPA can tentatively conclude on the basis of the Ford comments and our own measurements of exhaust systems temperatures that the mechanical trap is not a promising control technique.

Molten Carbonate Traps

Atomics International Division (AI) of Rockwell International commented on the general issue of sulfate traps and stated that they had developed and tested an exhaust scrubber device which has been effective in removing particulates from automobile exhaust gases. This scrubber works by passing the exhaust gas through a molten alkali metal carbonate mixture consisting of equal parts by weight of lithium, sodium and potassium carbonates. A calculation shows this salt mixture will require changing every 15,000 to 20,000 miles.

However, a major problem with this type of trap is potential emission of alkali carbonate itself by entrainment from the trap. Limited data from Atomics International indicate an emission rate at 60-70 mph corresponding to a 2.2% loss of the scrubbing salt over 15,000 miles. Additional work is required to determine the magnitude of these problems.

Exxon is examining sulfate traps under contract to EPA and feels the molten carbonate trap has low potential compared with other possible traps. They cite the above entrainment problem, mention that the trap cannot work until the salt is molten, and feel that the molten salt mixture is corrosive and hard to contain. Due to these probelms, Exxon does not plan to test molten carbonate traps in their program.

Metal Oxide and Other Metal Carbonate Traps

Metal oxides, such as calcium, aluminum, zinc, magnesium and manganese oxides are candidates for use in automotive sulfate traps. Metal carbonates such as calcium carbonate, can also be used. These substances react chemically with the sulfuric acid to form inert sulfate salts. A trap containing calcium carbonate functions similarly to one with calcium oxide in that the solid compound (calcium carbonate or calcium oxide) reacts with the sulfuric acid. A calcium carbonate trap is different from the molten carbonate trap discussed earlier which used molten salts at high temperatures. Metal oxide and calcium carbonate scrubbers are used to control stationary sources SO_2 emissions. Ford, GM, and Exxon commented on metal oxide sulfate traps.

Ford has done a paper study of metal oxide sulfate traps and feels calcium oxide would be an effective trapping agent. However, Ford calculates that 250 lbs. (a cube of 20 inches on an edge) of calcium oxide is required to control sulfate emissions over 50,000 miles. Periodic replacement of the calcium oxide at specified mileage intervals would decrease the size of the trap. Ford also commented that the high CO_2 content of the exhaust converts calcium oxide to calcium carbonate which is also an effective trapping agent. Ford has not done any testing with a calcium oxide sulfate trap.

Ford feels that a sulfate trap containing alumina is more promising. It would require 32 pounds of alumina over 50,000 miles. Alumina is the same substance used for catalyst pellets and readily reacts with sulfuric acid. However, Ford commented that attrition of the alumina could occur. Any development program for sulfate traps must measure for trap attrition products. Finally, Ford stated that a major design problem with alumina and other compounds is a suitable trap design to assure adequate contact between the alumina and the exhaust gas.

GM has designed and tested a 90 in^3 vehicle sulfate trap containing alumina. The sulfate trap was installed on a vehicle with a GM catalyst and tested over the FTP. GM stated that the results of the testing over the FTP were inconclusive due to low baseline emissions over the FTP without the trap. Clearly, the trap must be tested under conditions, such as 60 mph cruise, which result in high sulfate emissions. GM, using slightly different assumptions than Ford, calculates that 10-20 lbs. of alumina are needed over 50,000 miles.

Exxon commented that they have a laboratory program to test calcium oxide traps. Furthermore, Exxon is under contract with EPA to test and evaluate vehicle sulfate traps containing alumina, calcium oxide, or other promising materials. One potential problem with metal oxide traps is that the sulfate compound formed from reaction with the trapping media with SO_3 is larger in volume than the metal oxide. The trap must be designed to accommodate this expansion.

Almost all of the actual vehicle tests on sulfate traps have been done under at EPA contract with Exxon. A 25,000 mile test was run on a $CaO-SiO_2 - Na_2O$ trap which showed high removal of sulfate. However, due to expansion of the trap material as sulfates were trapped, a high pressure drop across the trap developed, making the vehicle almost inoperable. Another test with this sorbent in a different geometry for minimum pressure drop will be run. However, these results were very encouraging in that they show this trap has the capacity to control sulfates from 25,000 miles.

Despite the encouraging results it is not possible at this time to make any conclusions about the effectiveness or cost of sulfate traps, and more evaluation and testing is needed which will be done in the next year.

C.6.3 Other Approaches Suggested

The only other sulfate control technology suggested was by Chrysler Corporation, who recommended use of leaded fuel to reduce sulfate emissions from catalyst vehicles. However, Chrysler used the Method 8 absorption procedure for measuring sulfates. As explained earlier in this appendix, Method 8 can detect up to 25% of the SO_2 present as sulfate. Therefore, the results of Chrysler's tests are highly questionable.

Chrysler has run non-catalyst vehicles on unleaded and leaded fuels and found lower sulfate emissions with leaded fuel. (Chrysler is one of the few investigators to find significant levels of sulfate emissions from non-catalyst vehicles.) Use of leaded fuel can result in the formation of lead sulfate which is insoluble and not measured by the adsorption method. Lead sulfate also is thought to have less harmful health effects than soluble sulfates.

Chrysler feels that use of leaded gasoline in catalyst vehicles would result in formation of lead sulfate and significantly decrease soluble sulfate emissions. This conclusion is based on comparing sulfate emission results from running non-catalyst vehicles on leaded and unleaded fuel. However, sulfate emission tests were not run on catalyst vehicles with leaded fuel.

A major question to be resolved is whether catalyst-equipped vehicles can operate on leaded fuel without excessive catalyst deterioration. All data so far indicate that catalyst vehicles cannot operate on leaded fuel as it is currently made, containing both ethylene dibromide and ethylene dichloride scavengers. Chrysler feels that ethylene dibromide alone is a catalyst poison and that catalyst-equipped vehicles can perhaps operate satisfactorily on fuel containing lead alone or lead and ethylene dichloride. Both GM and Ford feel that lead alone irreversibly poisons catalysts. This issue has not yet been resolved. If it is found that catalysts can use fuel with lead alone with ehtylene dichloride, and if the engine will operate satisfactorily on such a fuel, further testing to determine if use of leaded fuel would decrease sulfate emissions would be desirable. At this point in time, it is our judgment that use of leaded fuel to lower sulfate emissions does not seem to be a viable option.